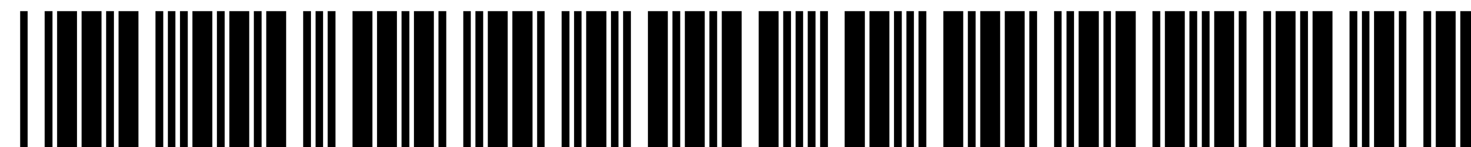

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Henstra et al.

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(45) **Date of Patent: Oct. 4, 2022**

(54) **ELECTRON DIFFRACTION HOLOGRAPHY**

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(72) Inventors: **Alexander Henstra**, Eindhoven (NL); **Yuchen Deng**, Eindhoven (NL); **Holger Kohr**, Eindhoven (NL)

(73) Assignee: **FEI Company**, Hillsboro, OR (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 362 days.

(21) Appl. No.: **16/835,129**

(22) Filed: **Mar. 30, 2020**

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(51) **Int. Cl.**

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G01N 33/38	(2006.01)
G03H 5/00	(2006.01)
H01J 37/04	(2006.01)
H01J 37/26	(2006.01)
G01N 23/207	(2018.01)

(52) **U.S. Cl.**

CPC ***G01N 23/207*** (2013.01); ***G01N 33/385*** (2013.01); ***G03H 5/00*** (2013.01); ***H01J 37/04*** (2013.01); ***H01J 37/26*** (2013.01); *G01N 2223/0566* (2013.01); *G01N 2223/064* (2013.01); *G03H 2224/04* (2013.01); *H01J 2237/2614* (2013.01)

(58) **Field of Classification Search**

CPC G01N 23/207; G01N 33/385; G01N 2223/0566; G01N 2223/064; G03H 5/00; G03H 2224/04; H01J 37/04; H01J 37/26; H01J 2237/2614

USPC 250/306, 307, 309, 310, 311

See application file for complete search history.

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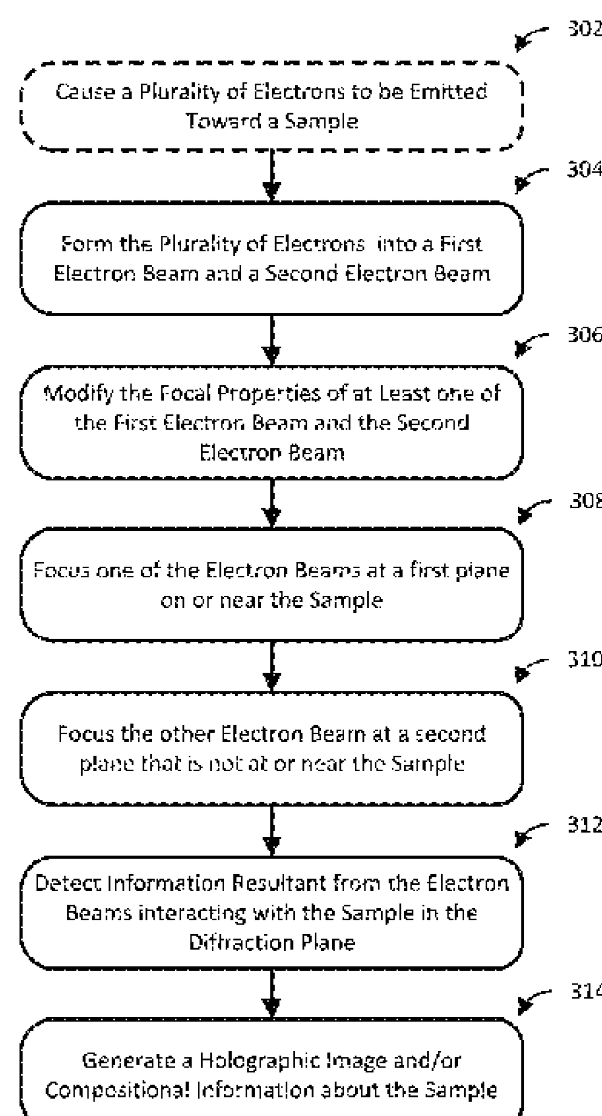
Primary Examiner — Nicole M Ippolito

(57) **ABSTRACT**

Methods for using electron diffraction holography to investigate a sample, according to the present disclosure include the initial steps of emitting a plurality of electrons toward the sample, forming the plurality of electrons into a first electron beam and a second electron beam, and modifying the focal properties of at least one of the two beams such that the two beams have different focal planes. Once the two beams have different focal planes, the methods include focusing the first electron beam such that it has a focal plane at or near the sample, and focusing the second electron beam so that it is incident on the sample, and has a focal plane in the diffraction plane. An interference pattern of the first electron beam and the diffracted second electron beam is then detected in the diffraction plane, and then used to generate a diffraction holograph.

20 Claims, 16 Drawing Sheets



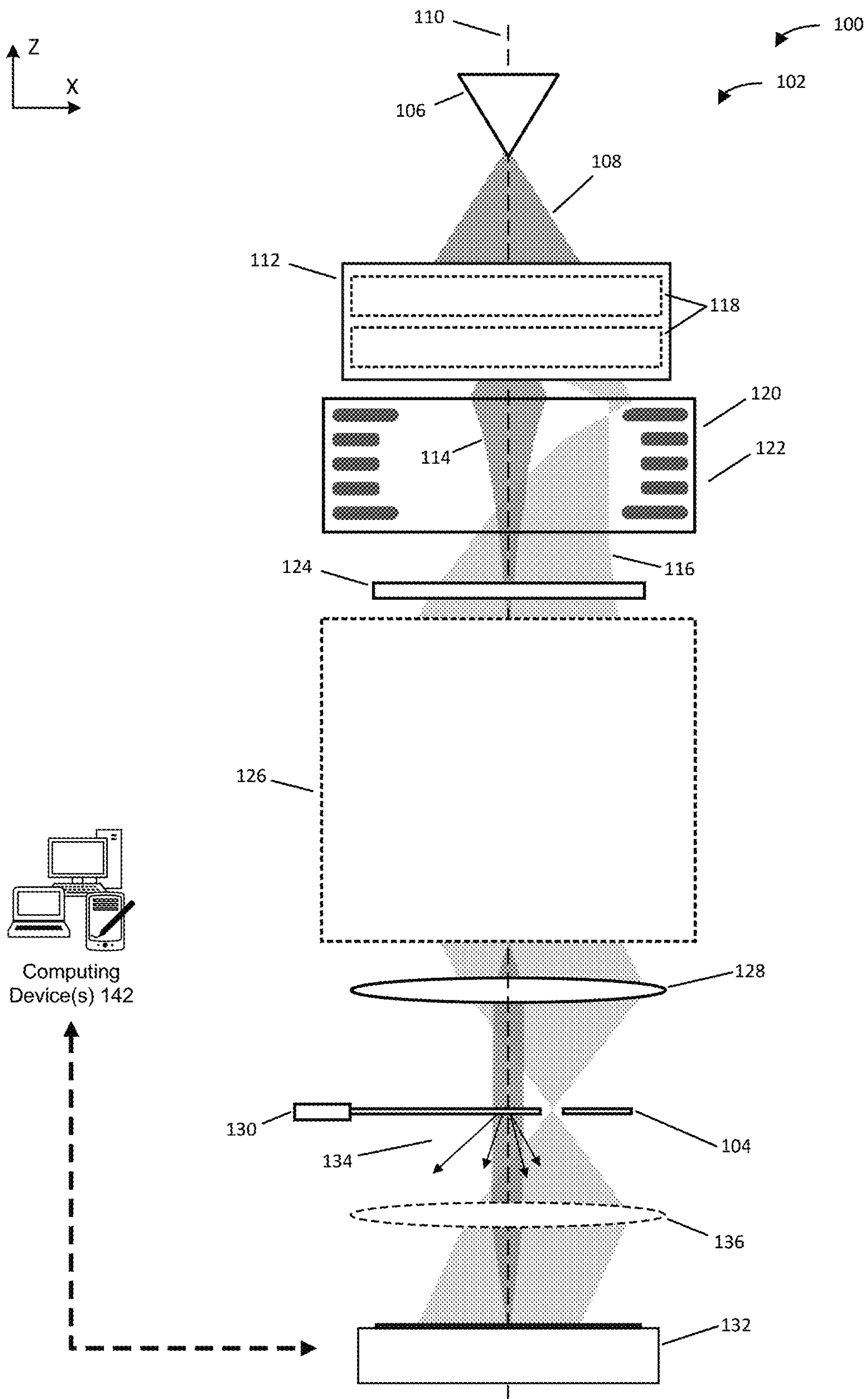


FIG. 1

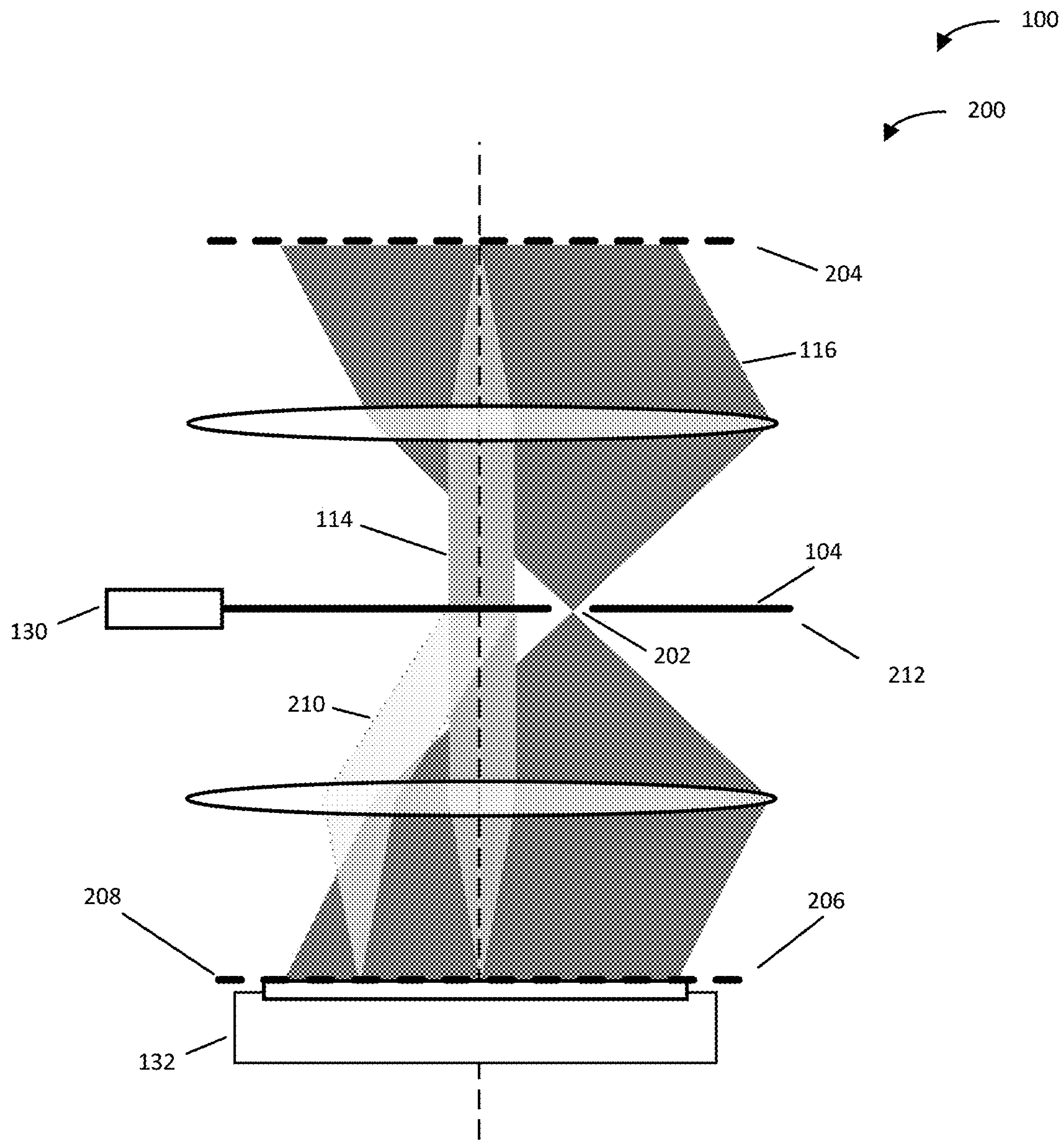


FIG. 2A

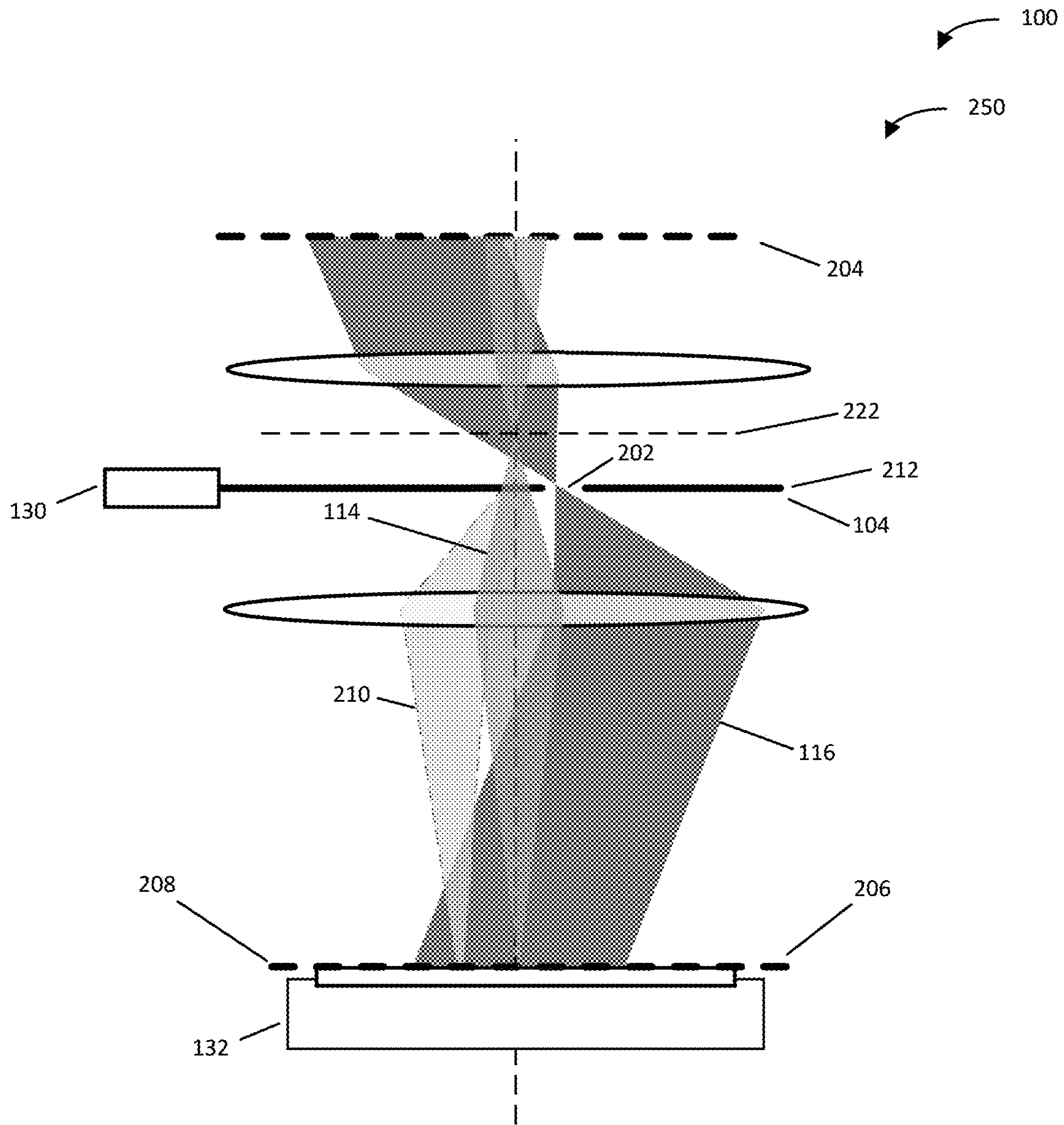


FIG. 2B

200

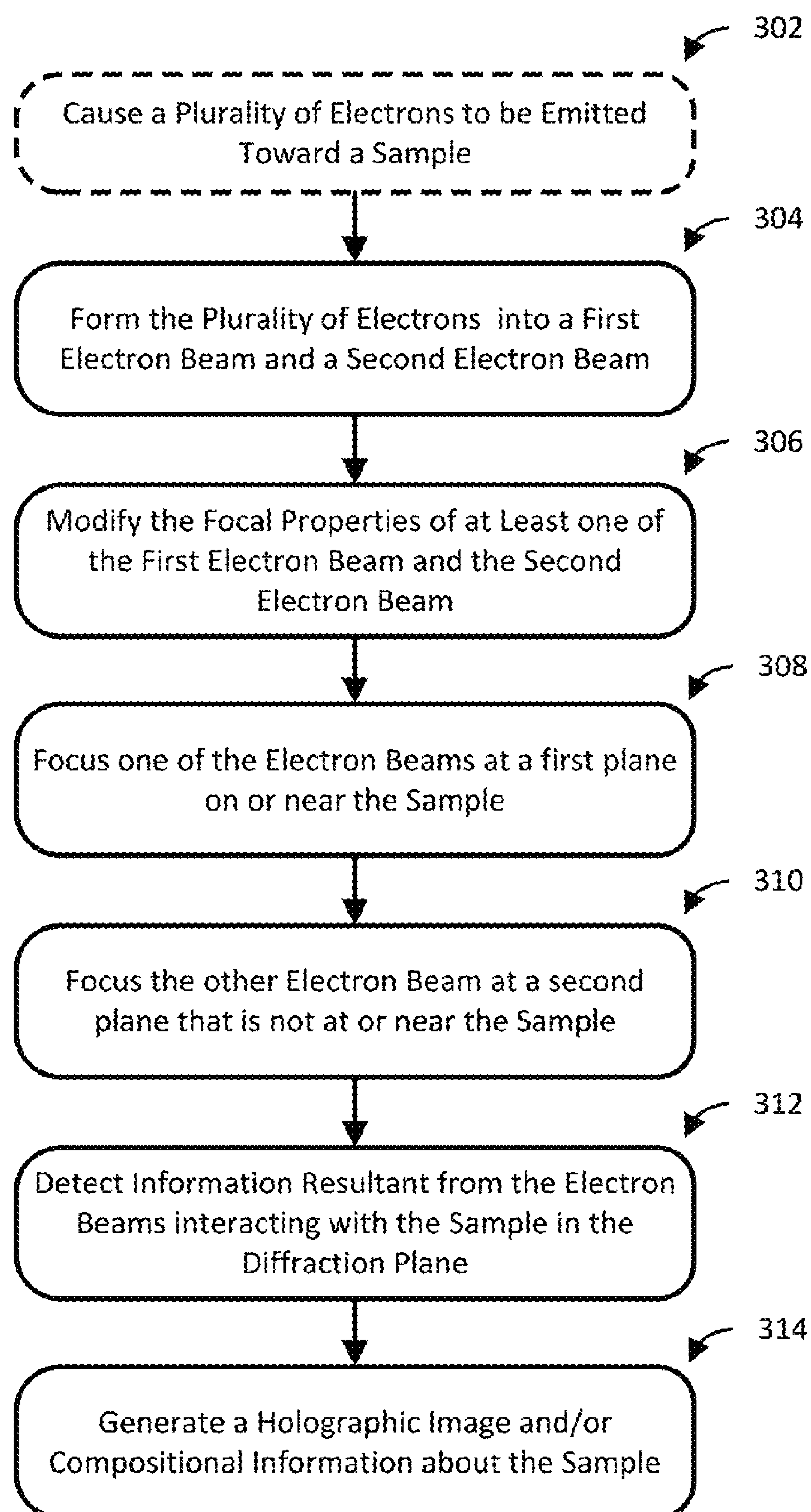


FIG. 3

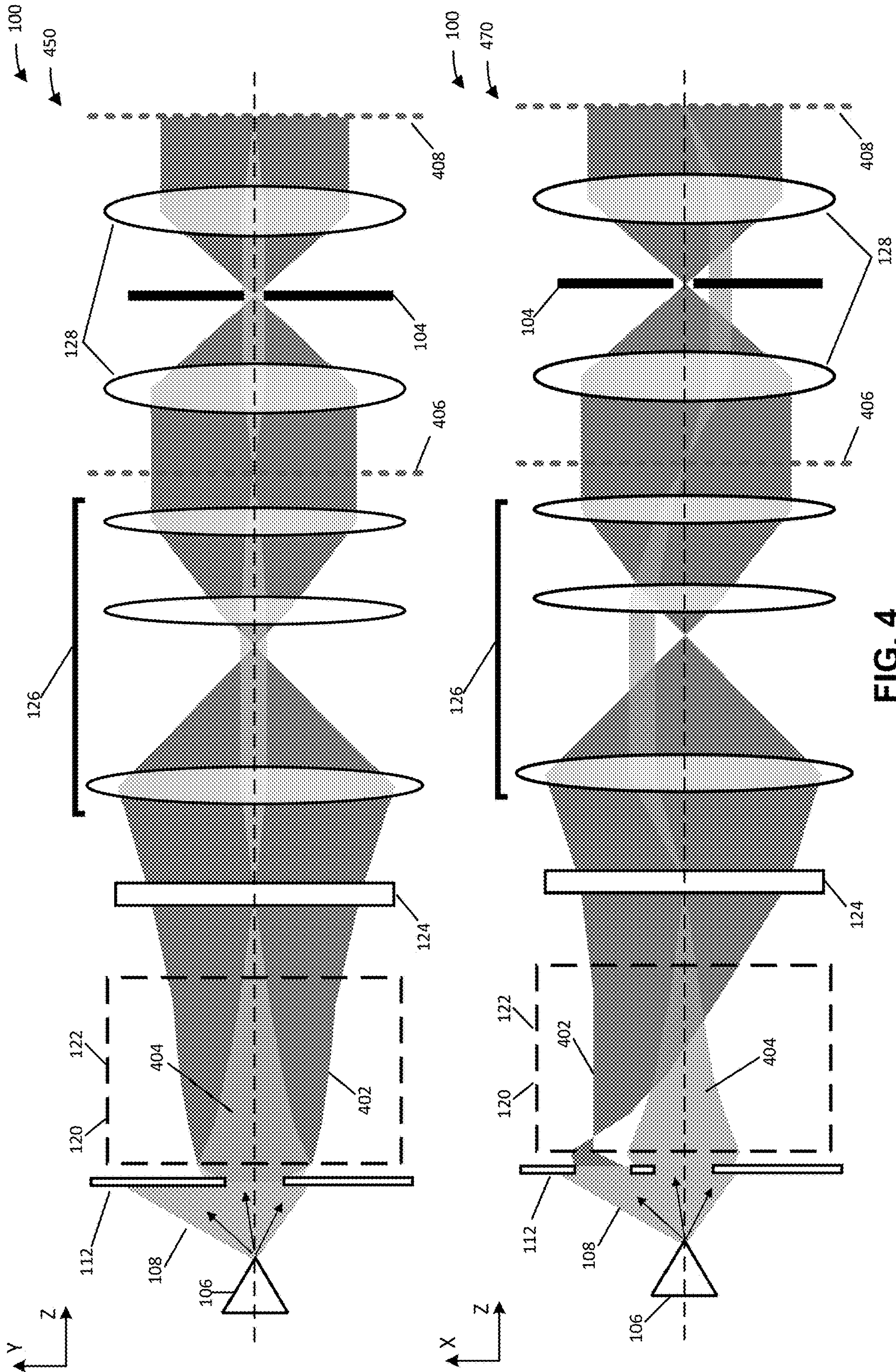


FIG. 4

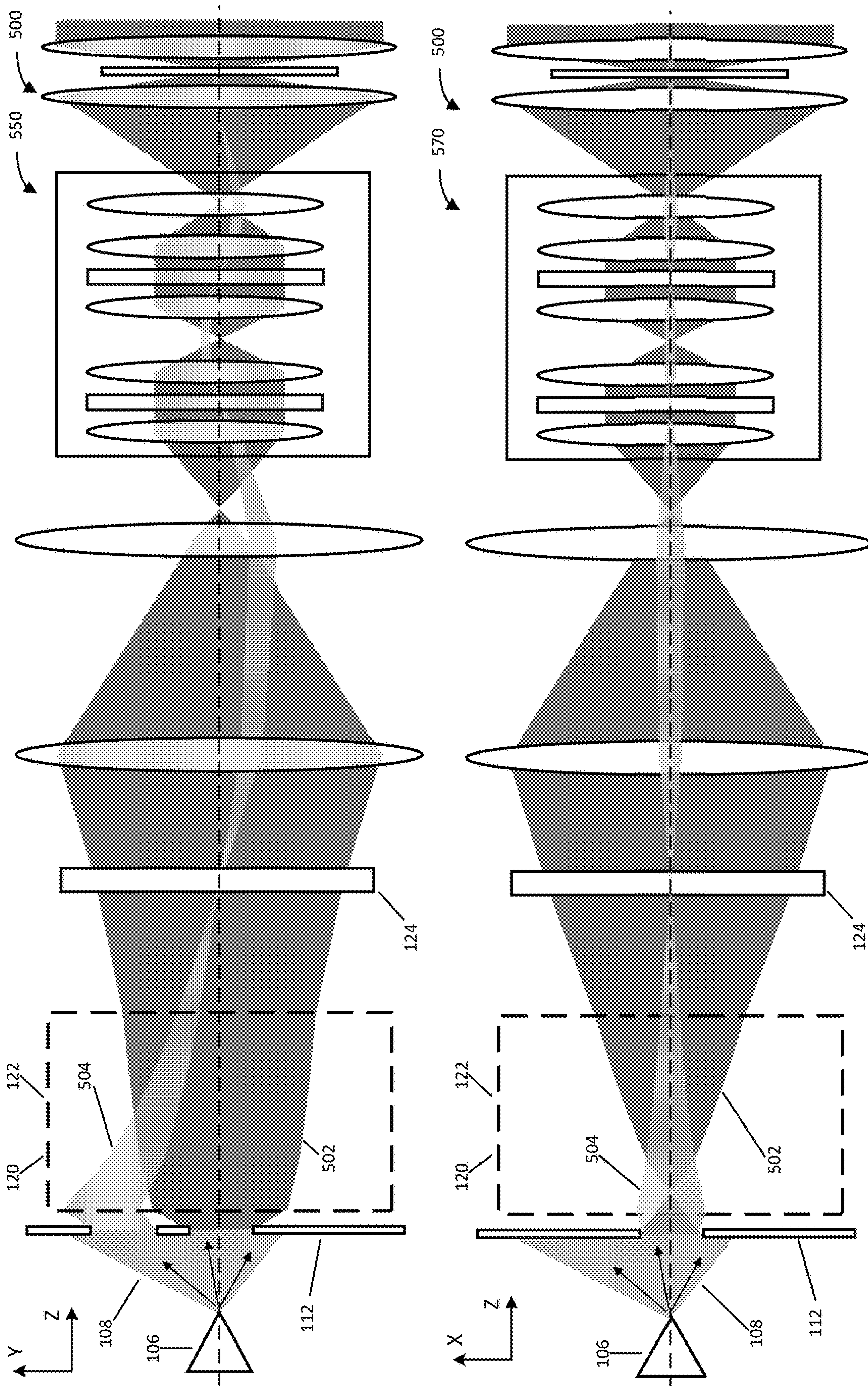


FIG. 5

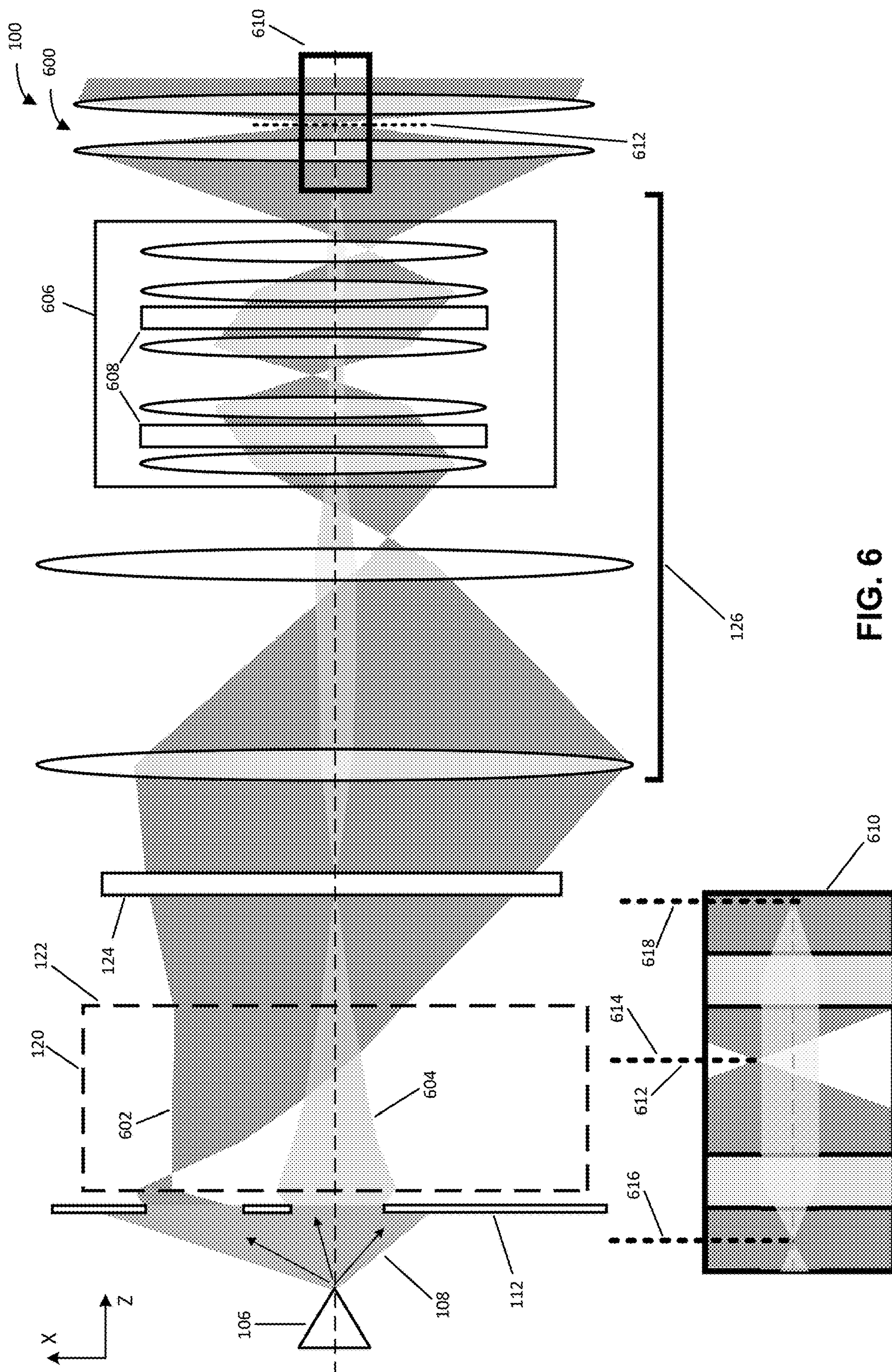


FIG. 6

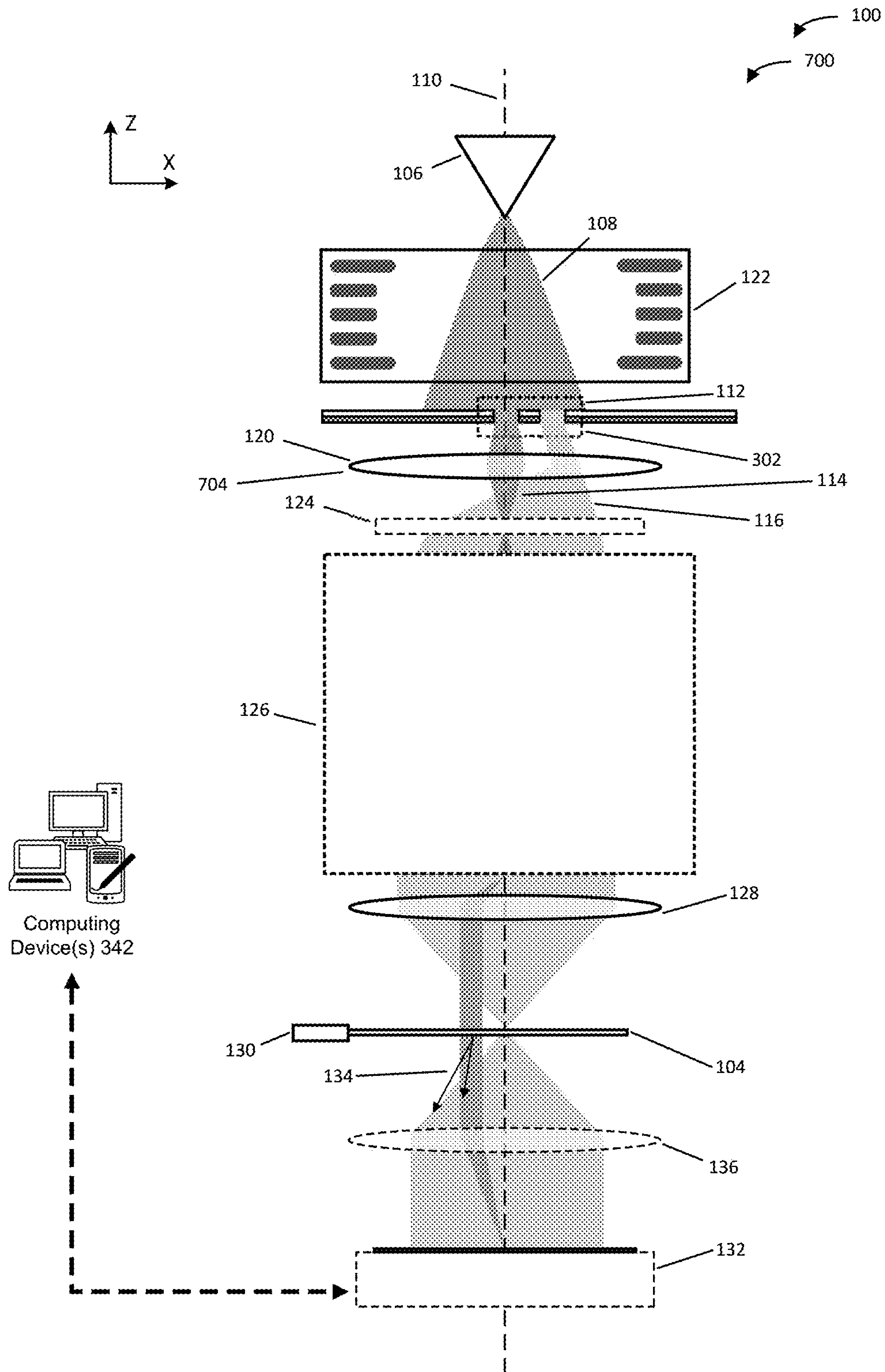


FIG. 7

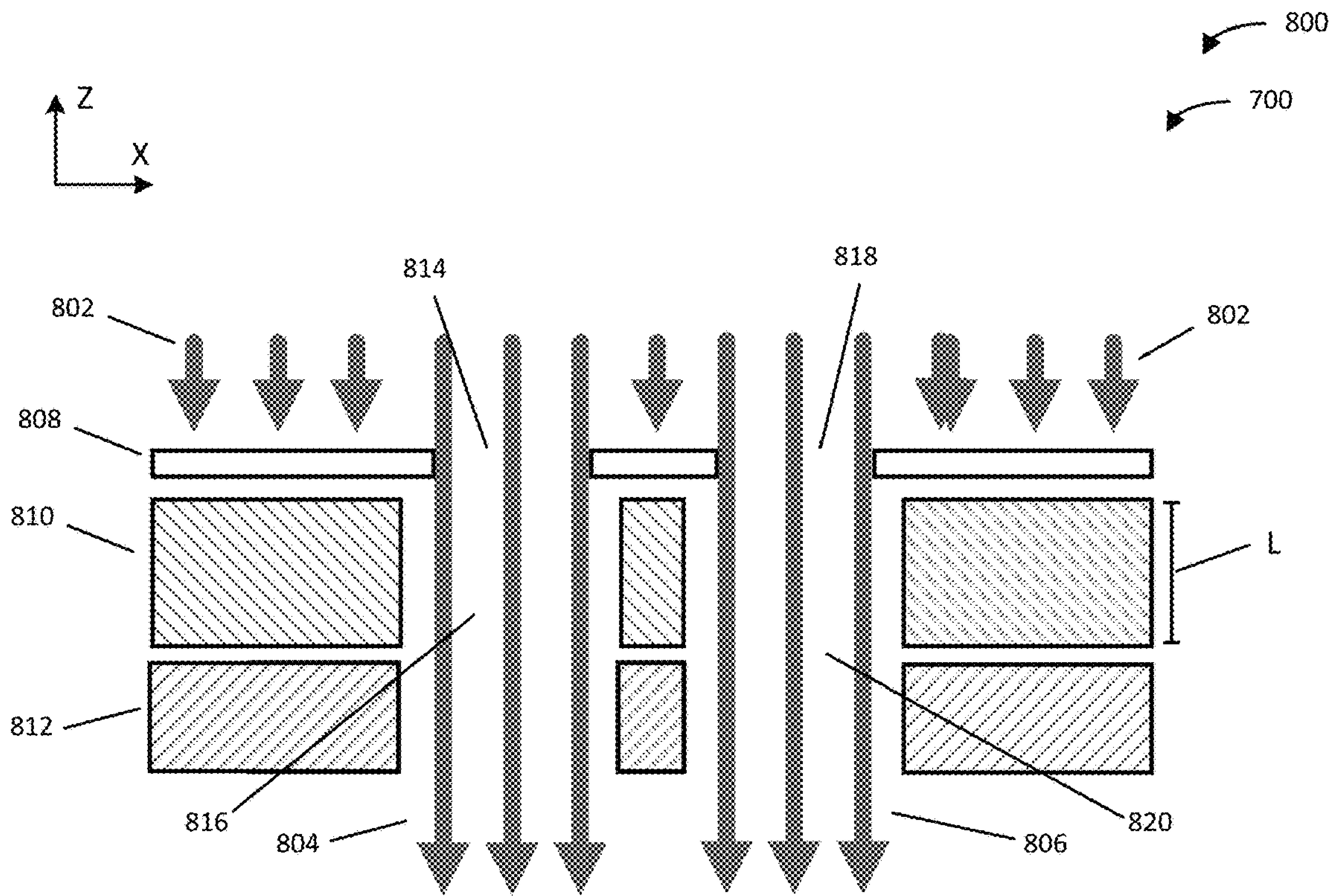


FIG. 8

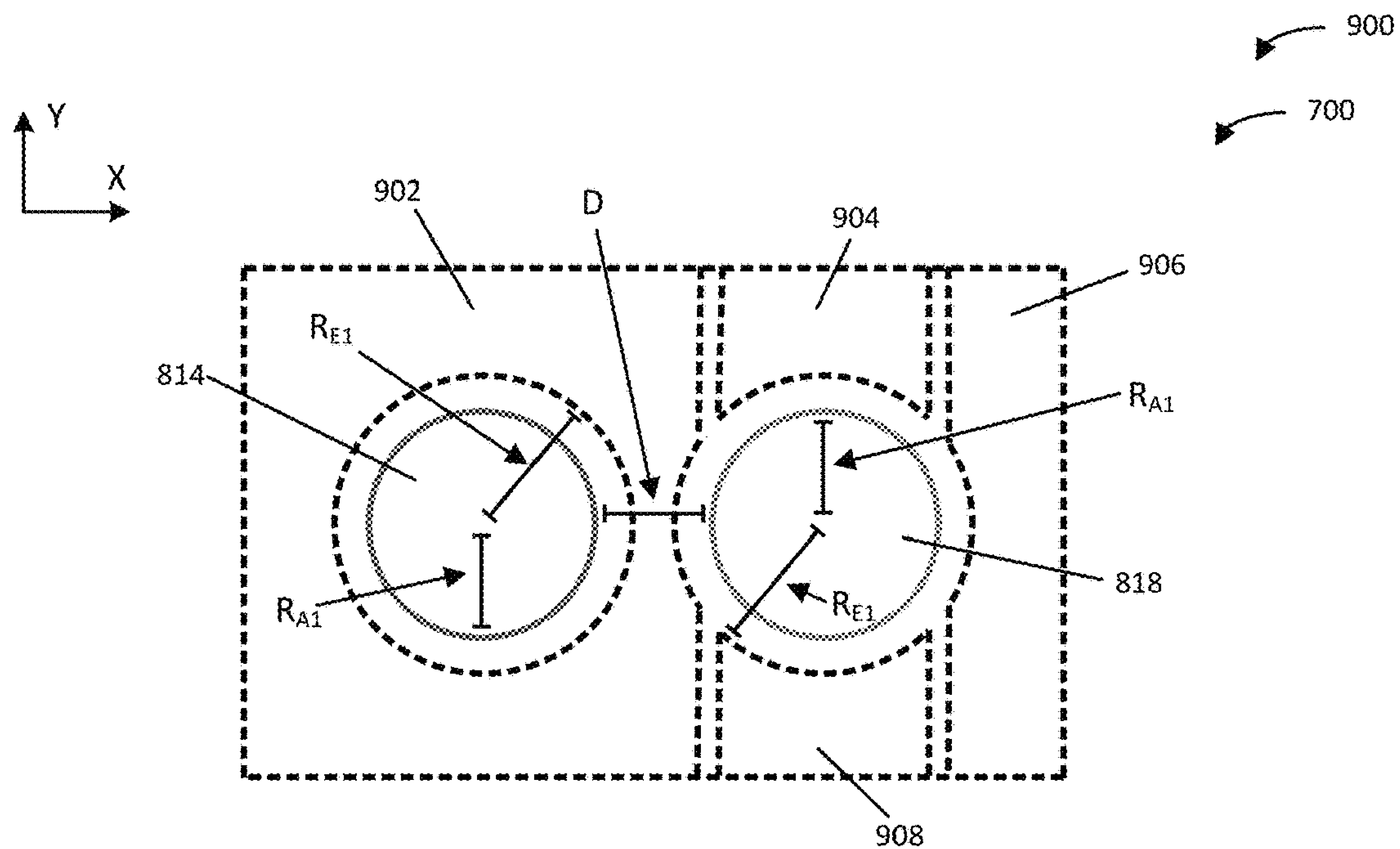


FIG. 9

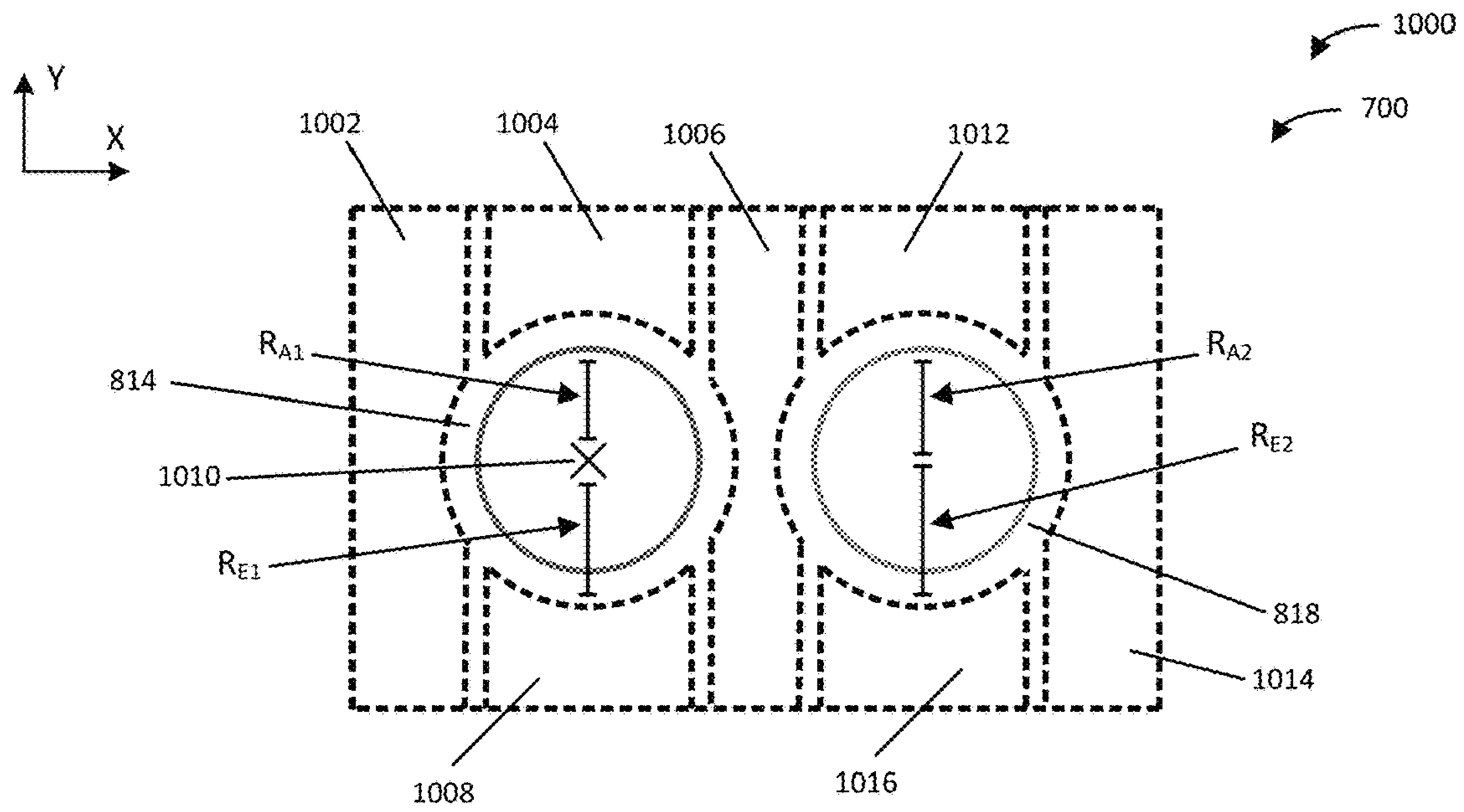


FIG. 10

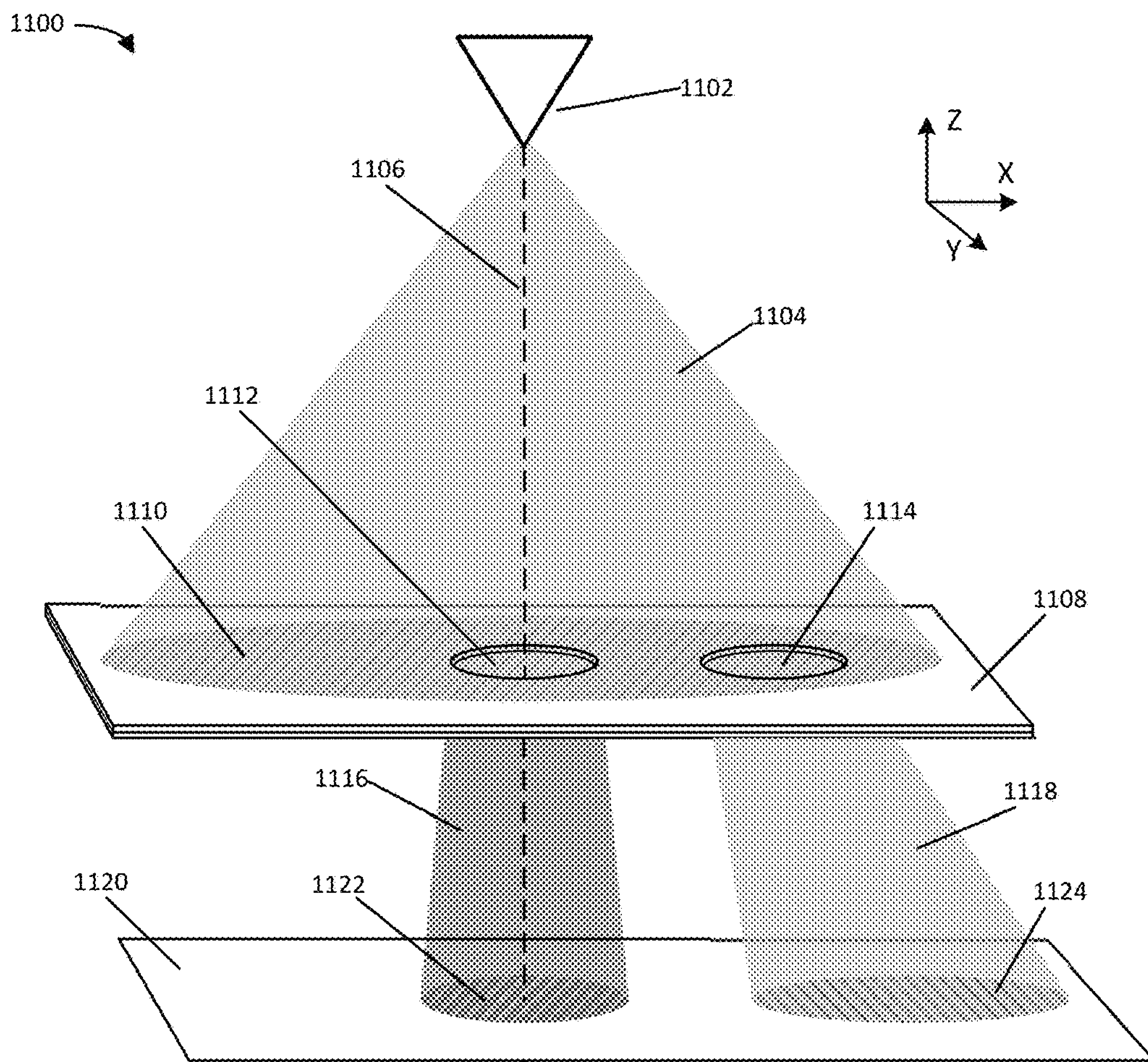


FIG. 11

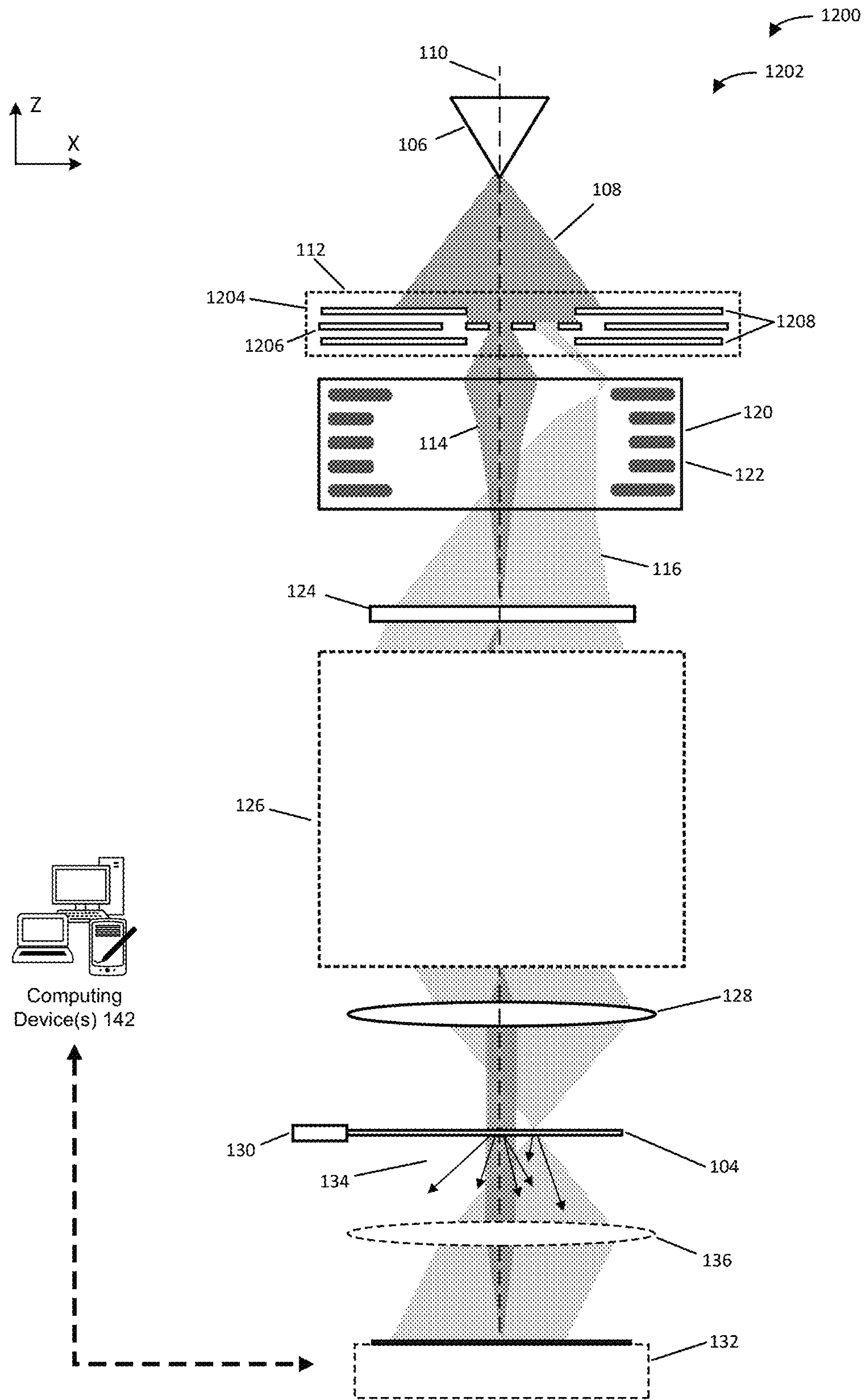


FIG. 12

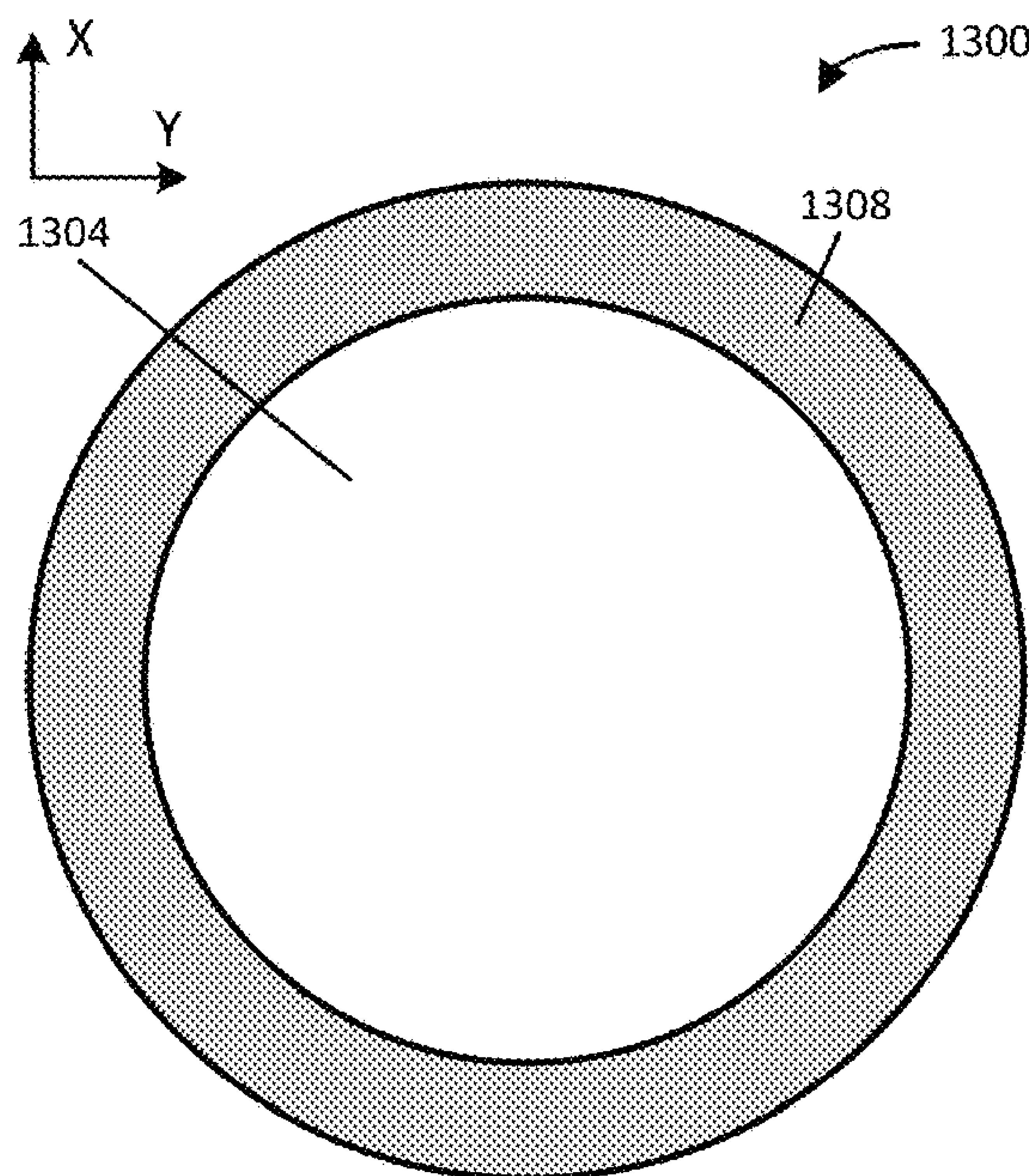


FIG. 13

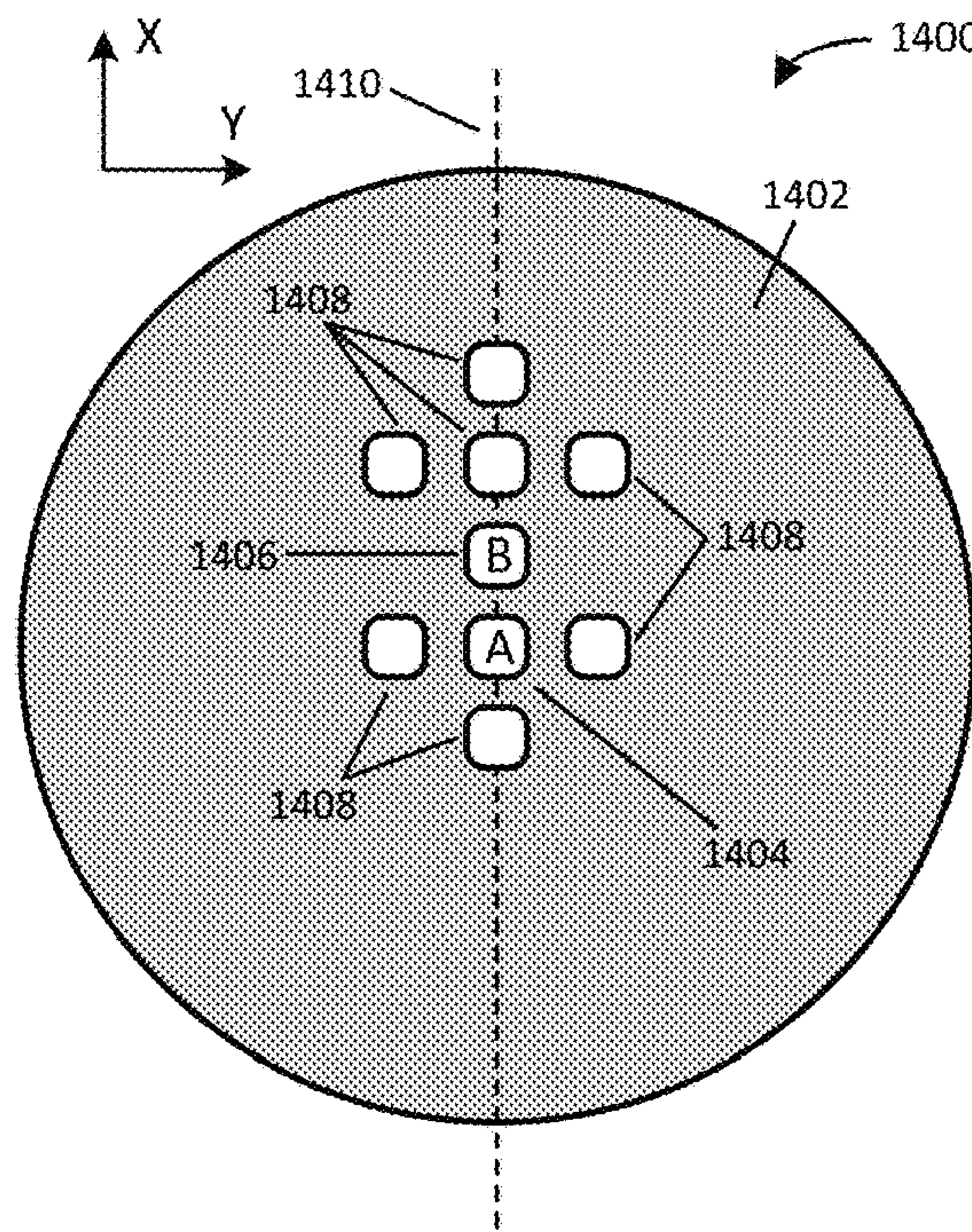


FIG. 14

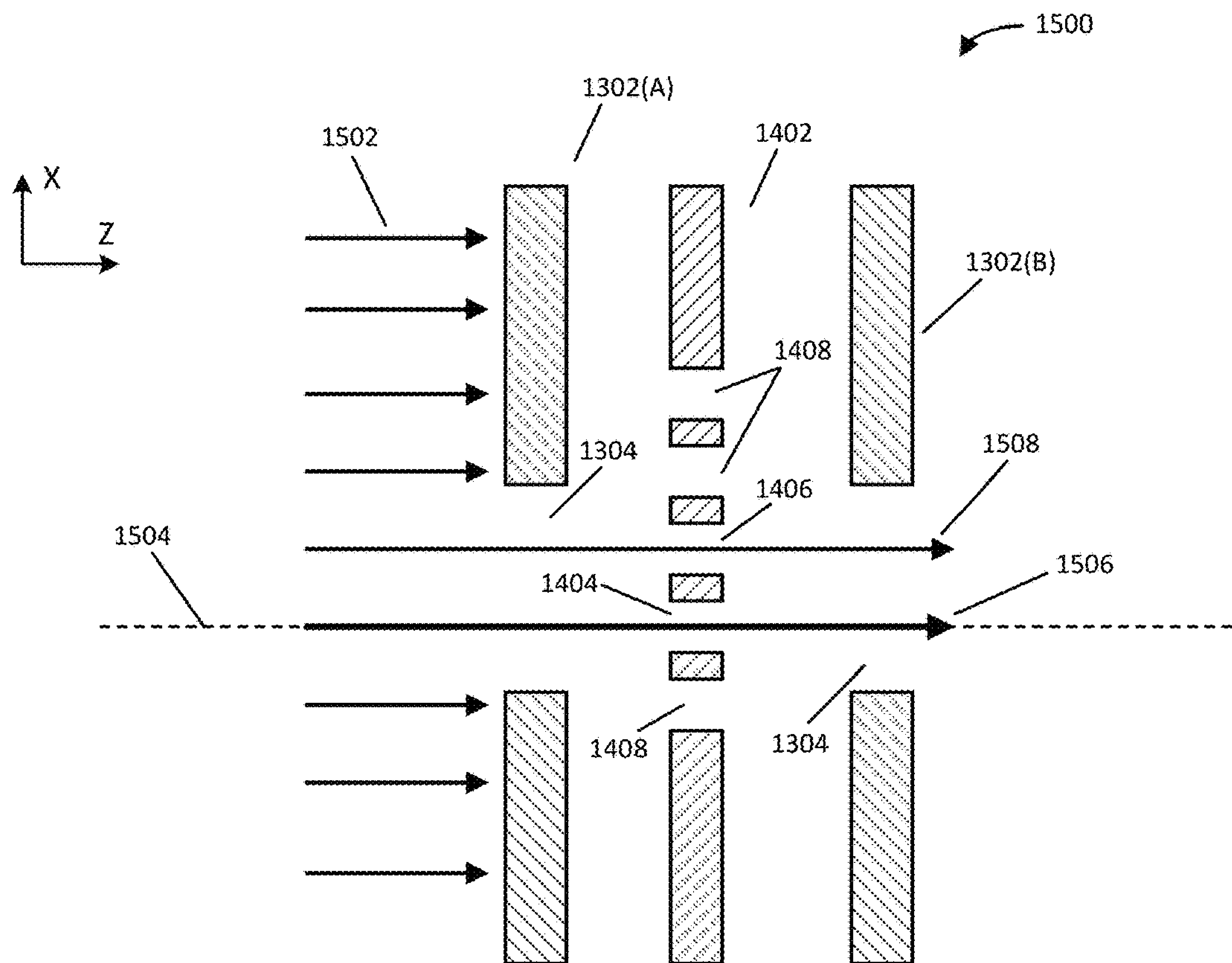


FIG. 15

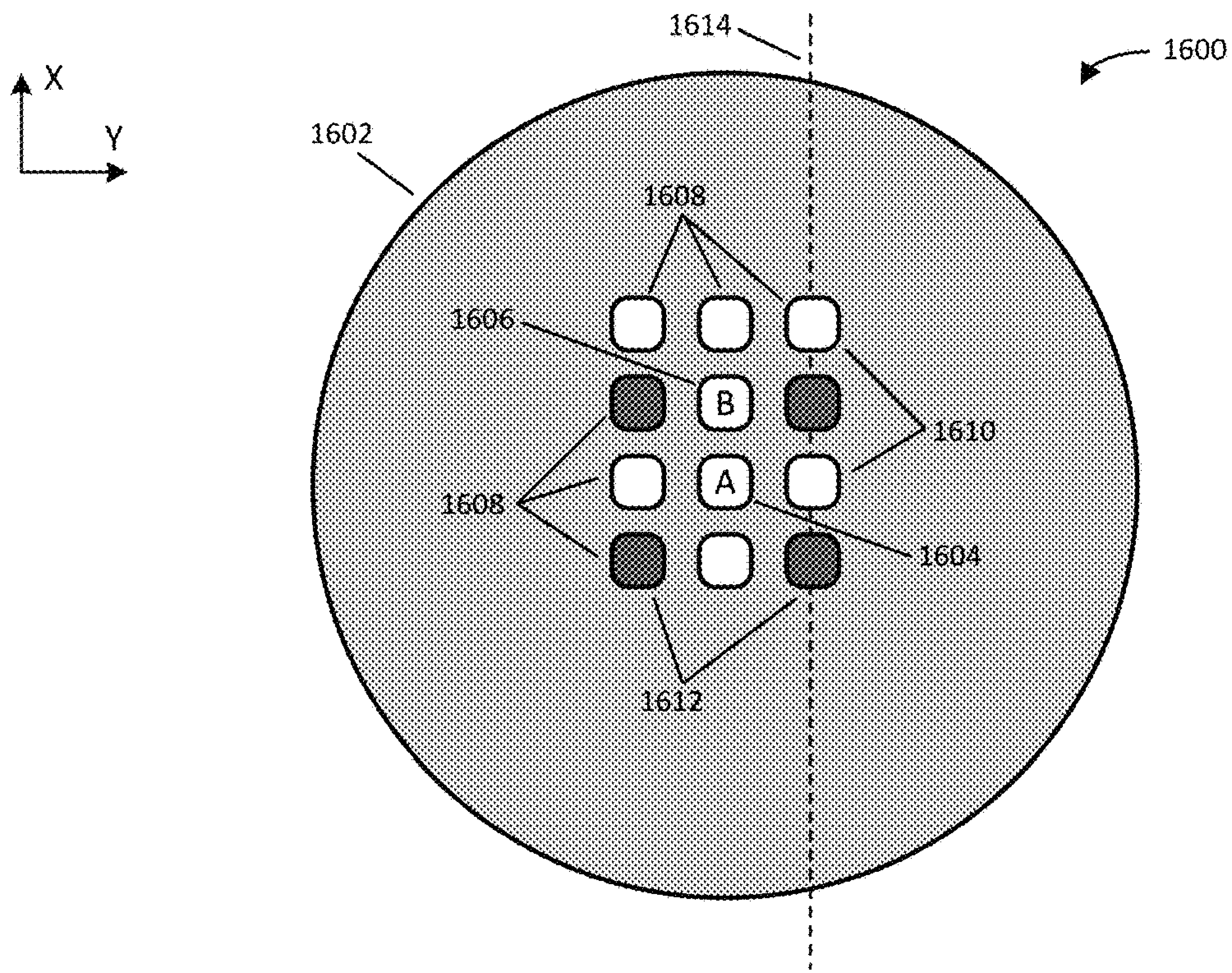


FIG. 16

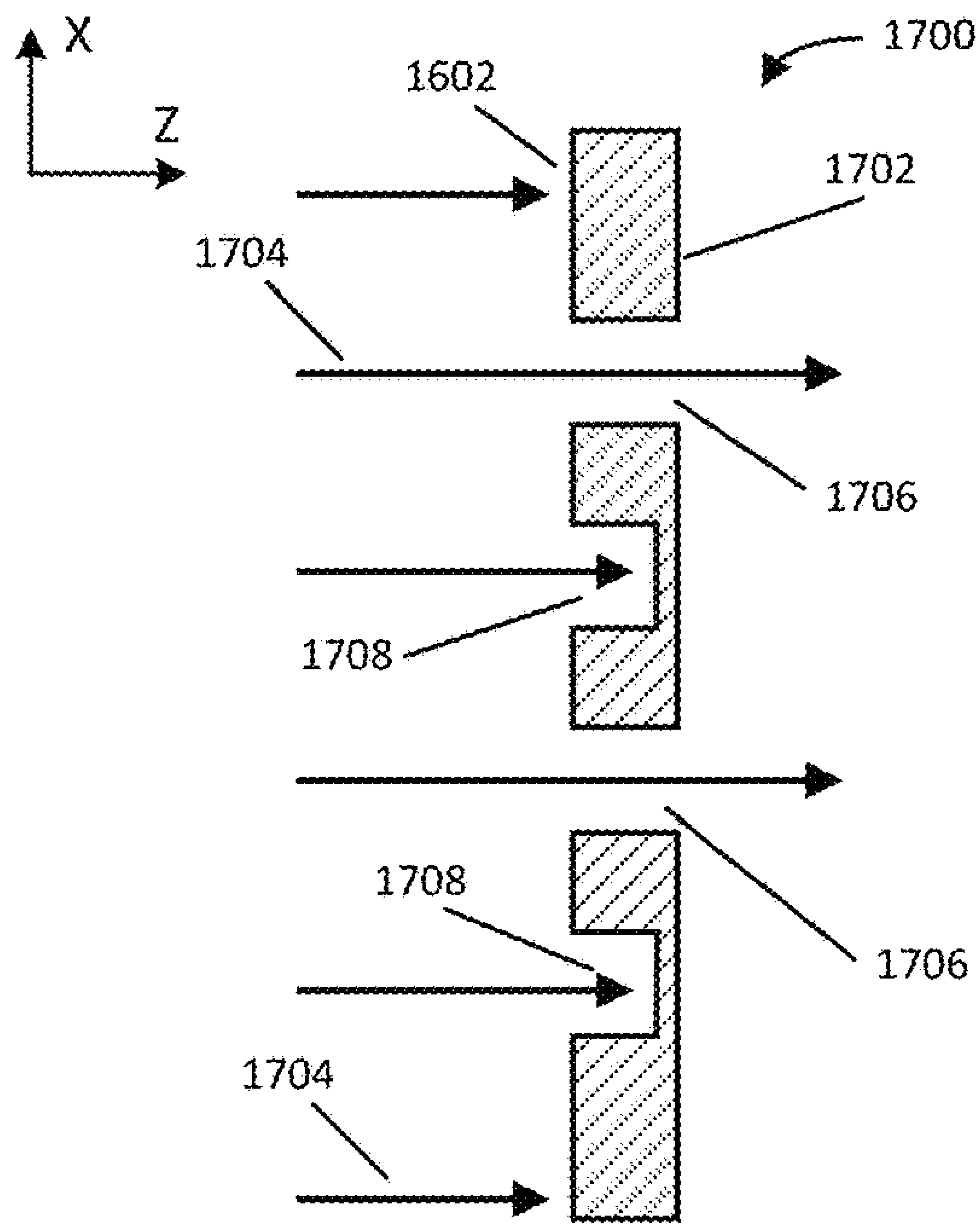


FIG. 17

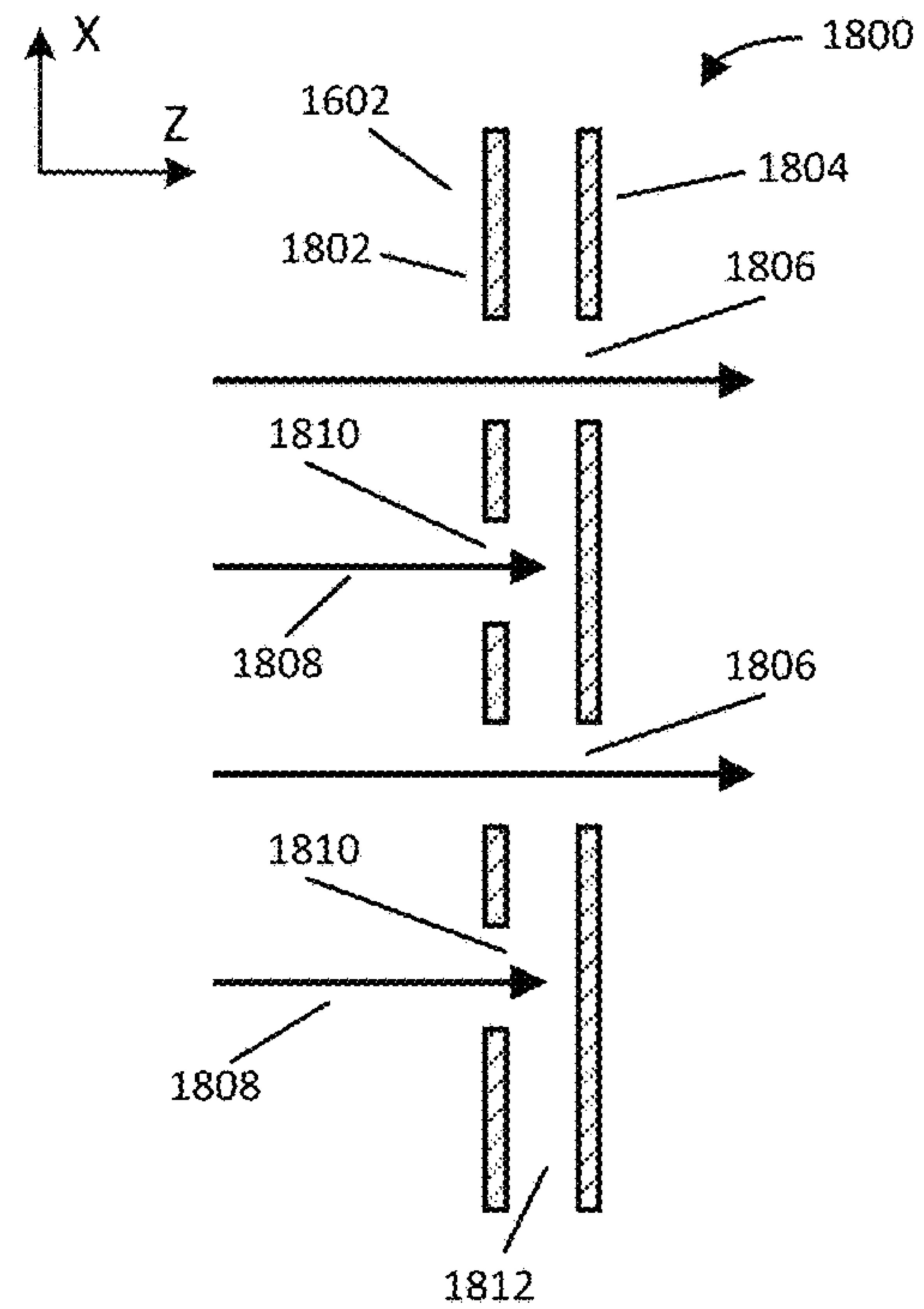


FIG. 18

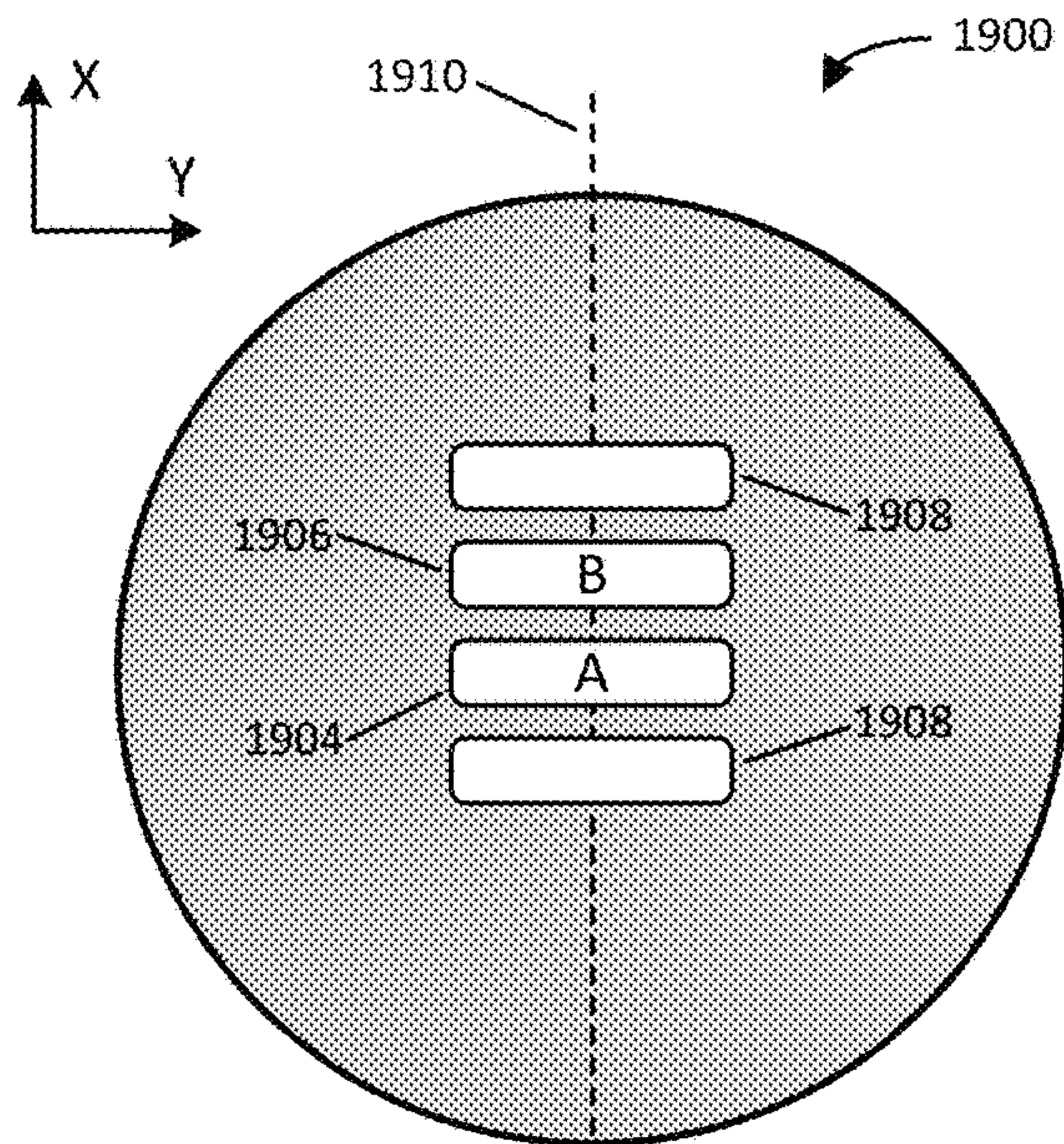


FIG. 19

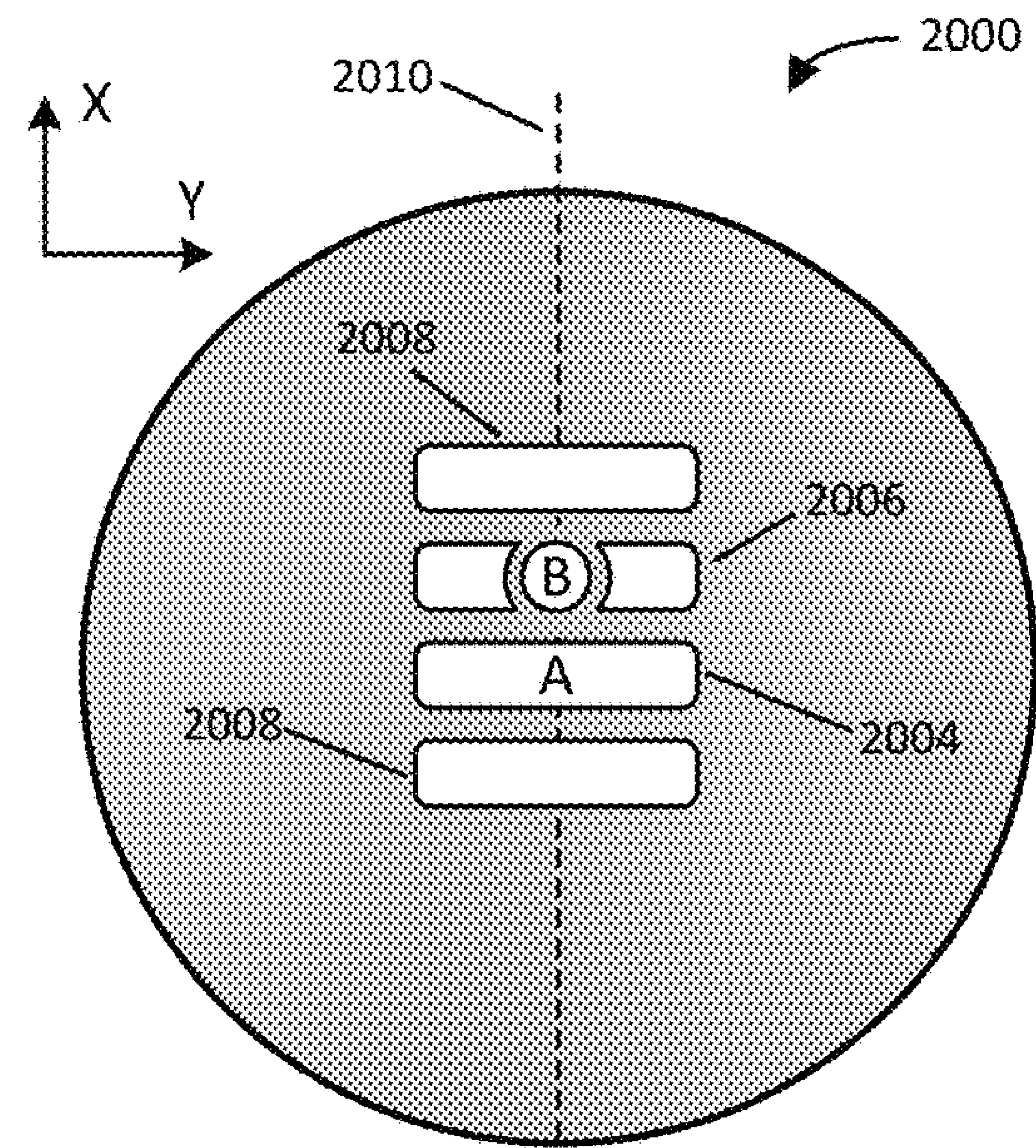


FIG. 20

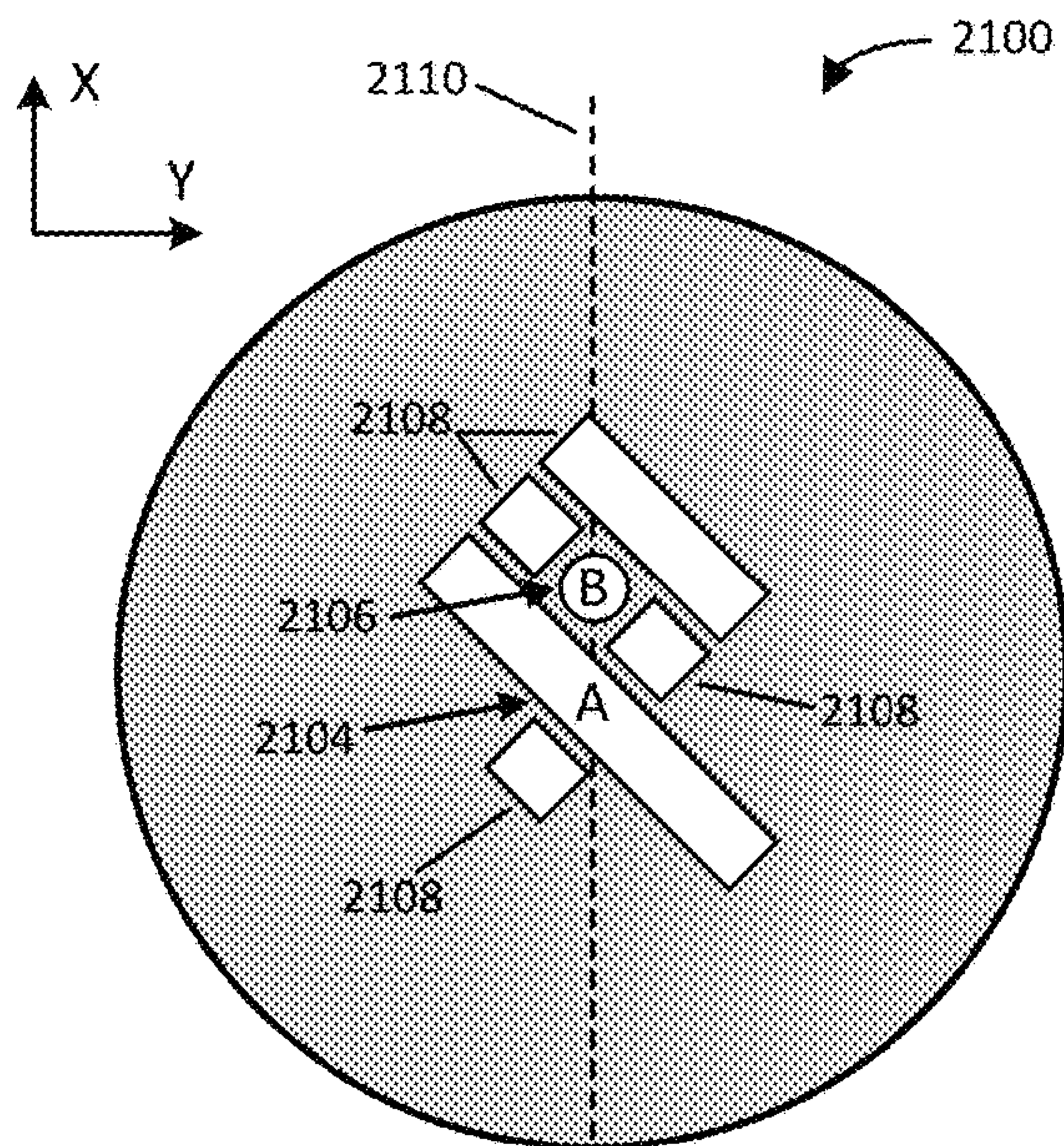


FIG. 21

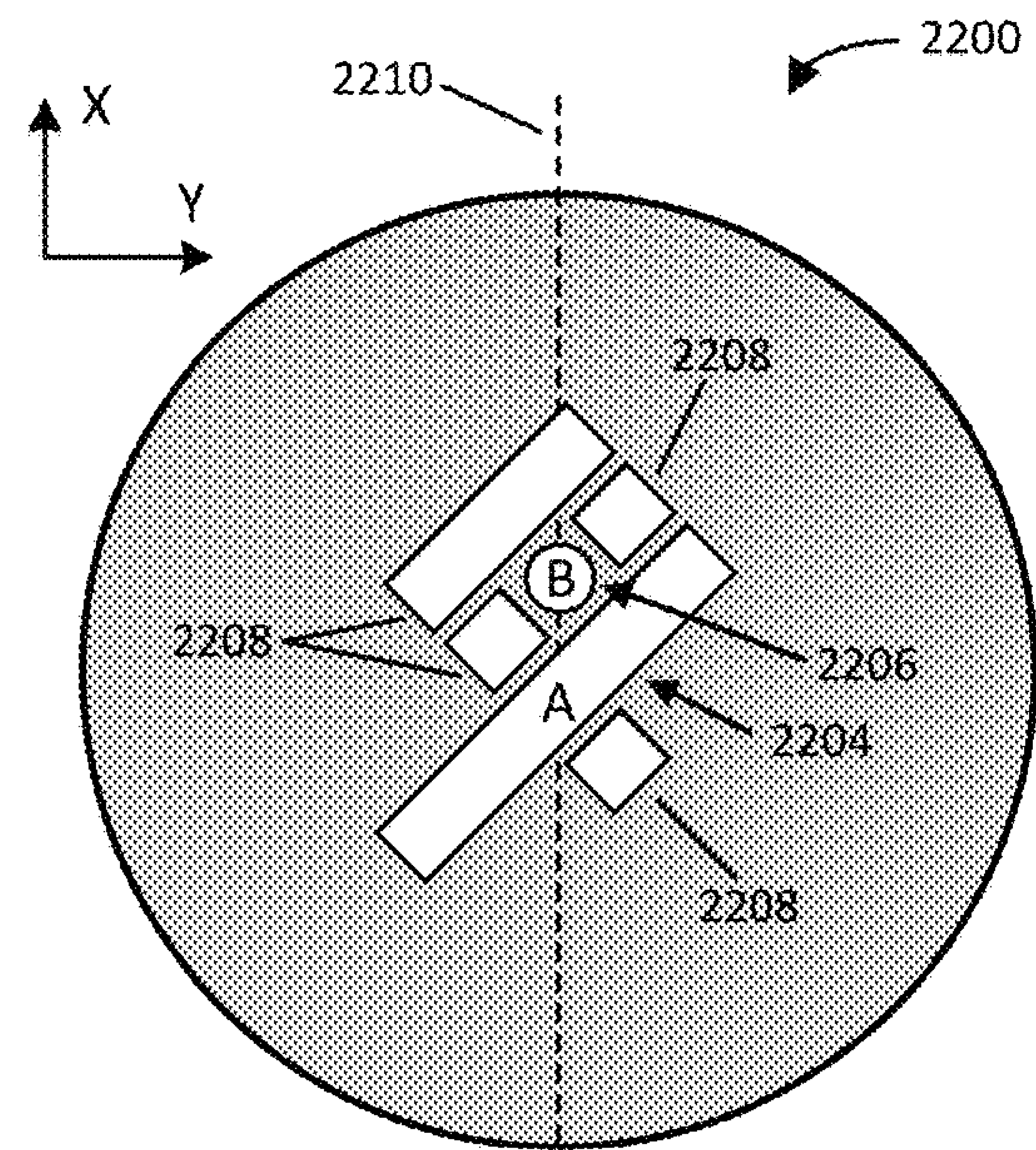


FIG. 22

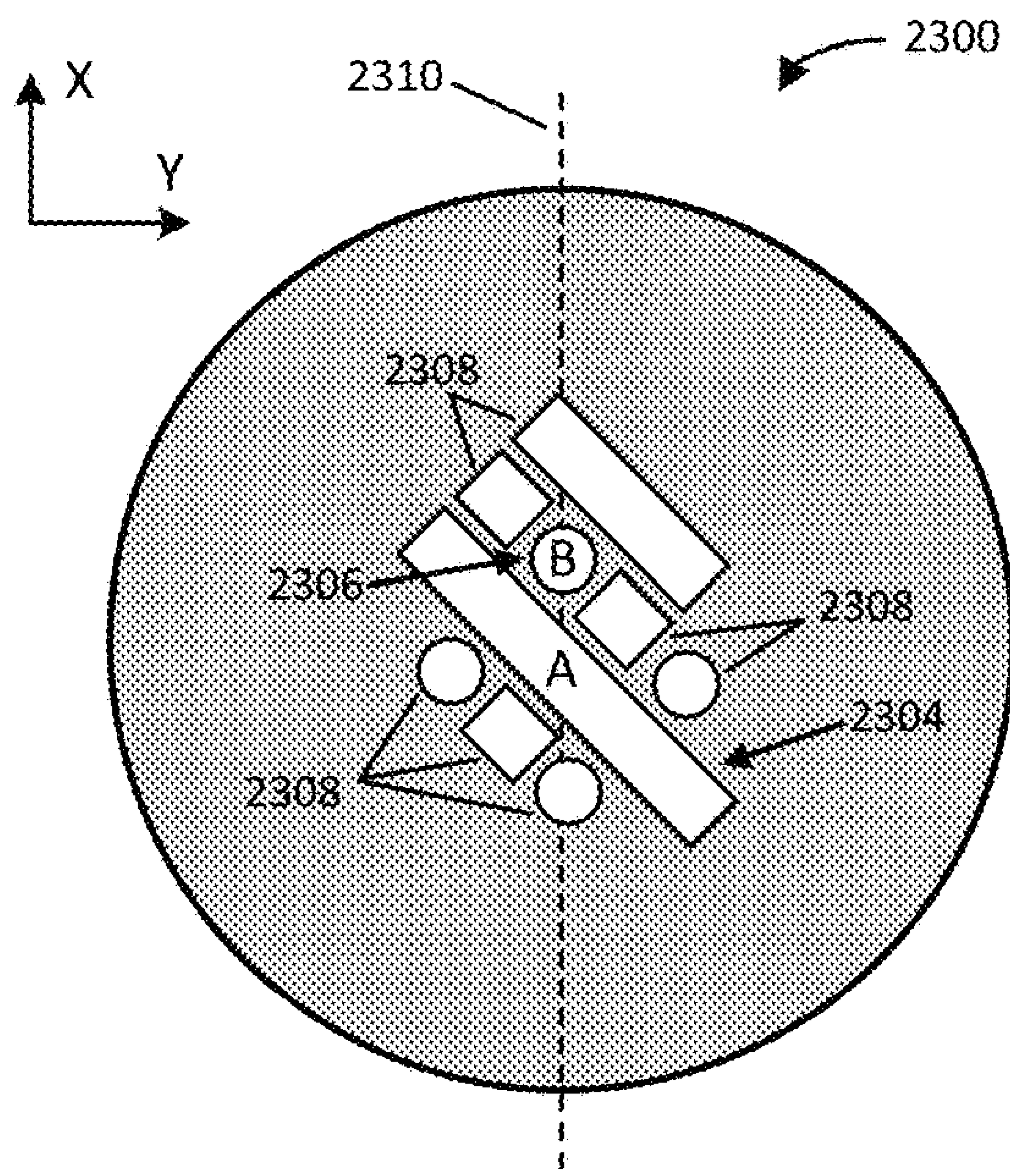


FIG. 23

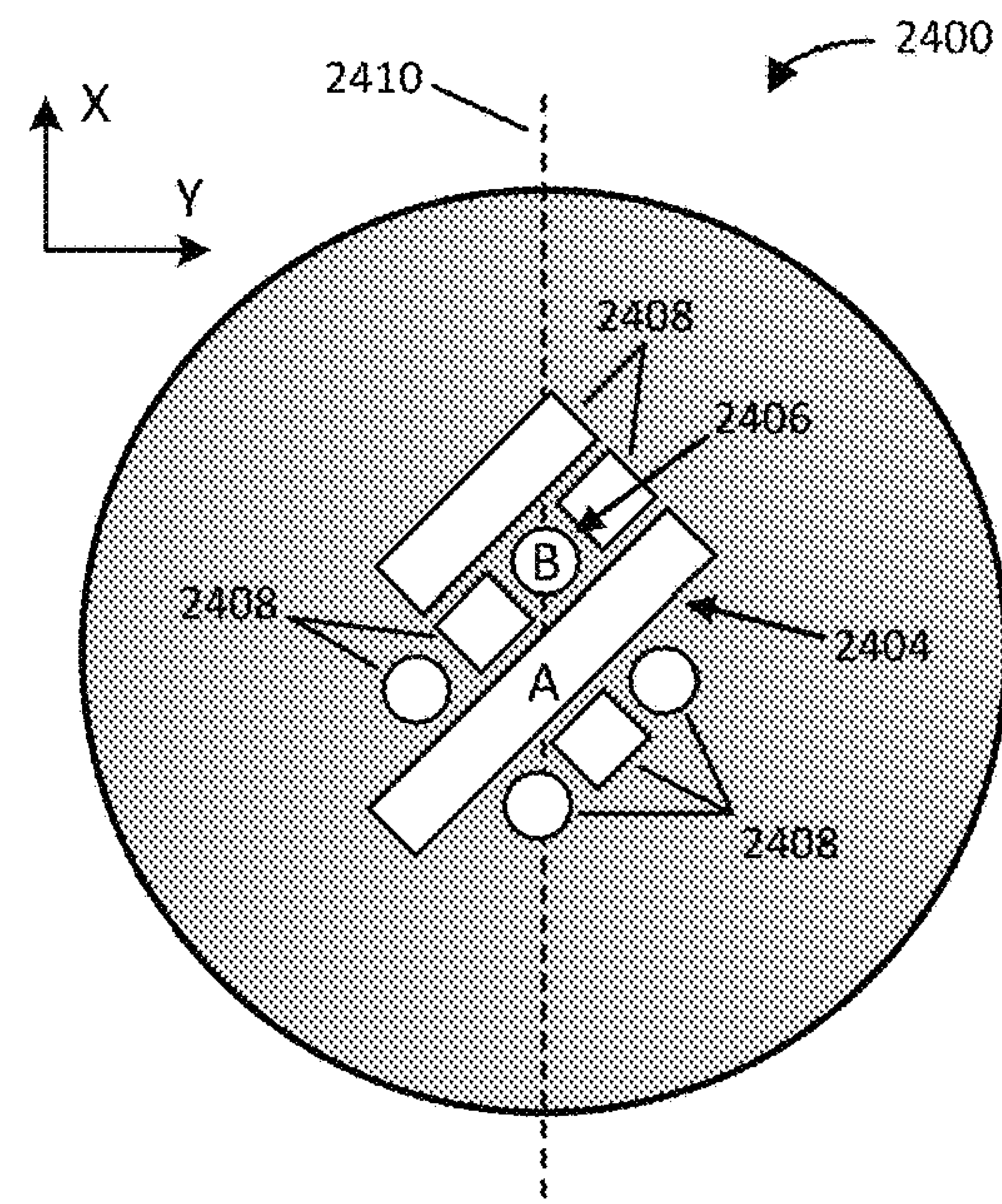


FIG. 24

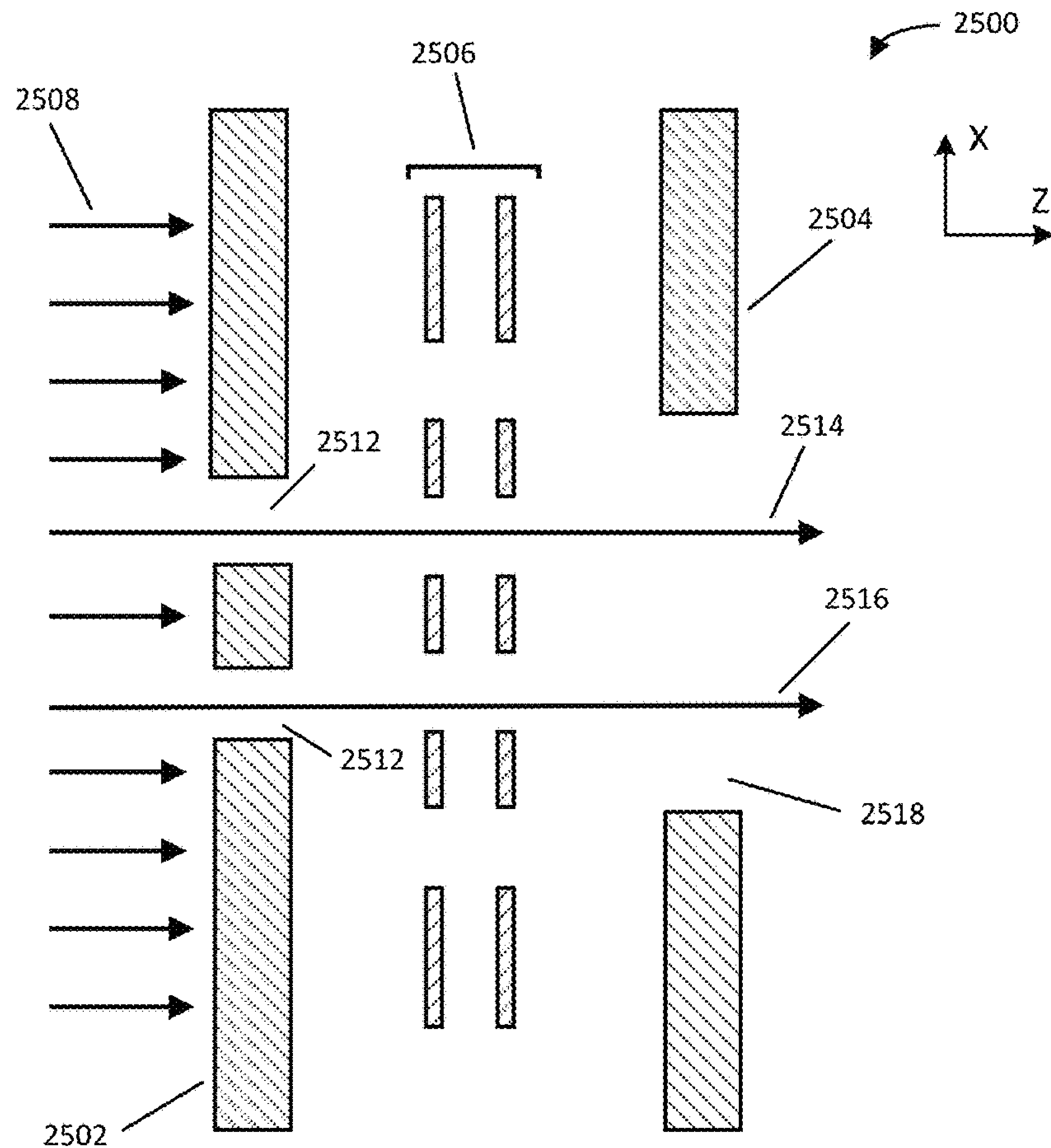


FIG. 25

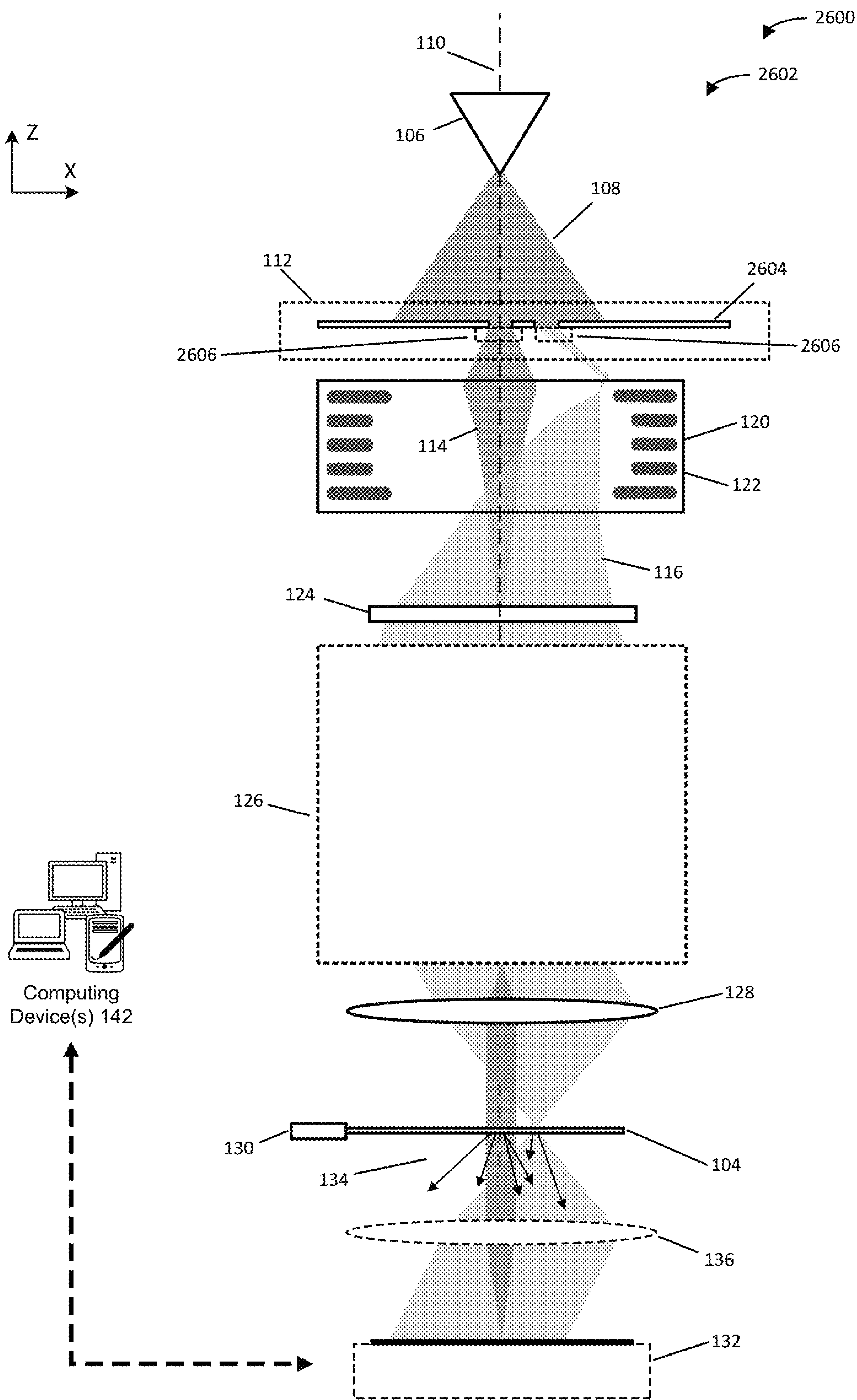


FIG. 26

ELECTRON DIFFRACTION HOLOGRAPHY

CROSS REFERENCE TO RELATED APPLICATIONS

This application relates to patent application Ser. No. 16/834,963, filed on Mar. 30, 2020, titled "Dual Beam Bifocal Charged Particle Microscope", by Henstra et al., which is incorporated herein by reference in its entirety and for all purposes.

BACKGROUND OF THE INVENTION

A transmission electron microscope can be operated in Selected Area Electron Diffraction (SAED) mode, in which the diffraction plane is imaged onto a camera. This mode is especially useful for the study of crystalline material, in which case crystallographic information can be obtained. In the case where a single (monocrystalline) crystal is studied, diffraction patterns can even be used for the reconstruction of the 3D potential distribution of the atoms that constitute the crystal. For isotropic resolution, diffraction patterns need to be collected for all orientations of the crystal. In practice, data is usually collected while continuous tilting of the crystal over an appropriate range. This technique is called micro Electron Diffraction, or 3D electron crystallography. Diffraction peak intensities only provide structure factor amplitudes, phase information is missing and has to be obtained by other methods. If the diffraction peaks extend to high resolution (order 1 Angstrom) and the number of atoms in the unit cell is limited, phases can be derived computationally using certain constraints (atomicity, phase correlations). For larger molecules and lower resolution, a method called 'molecular replacement' is often used, using phase information from homologue structures as initial guess for the phase. For entirely unknown structures this cannot be done. Other popular phasing methods as used in X-ray crystallography (anomalous dispersion, isomorphous replacement) are not well applicable for electron crystallography.

Moreover, current transition electron microscopy (TEM) systems operating in electron diffraction mode struggle to obtain the full exit wave (of the specimen i.e., the complex exit wave including both amplitude and phase information). Instead, TEM systems operating in electron diffraction mode merely record the intensity of scattered and/or diffracted electrons at various points in a detector positioned in a magnified image of the diffraction plane, and then generate a reconstruction of the specimen based only on the detected intensity values (i.e., without phase information). This inability to determine phase information limits the types of objects that can be effectively imaged by TEM systems operating in electron diffraction mode. While current electron holography setups exist that allow for both intensity and phase information to be obtained via superposition of a coherent wave with the electrons scattered and/or diffracted electrons by an object, these systems are unable to generate results from electrons scattered and/or diffracted electrons that are detected in the diffraction plane. For example, off-axis holography is a well-known technique that has been developed to obtain full exit waves of a specimen, but currently this technique can only be only applied where the specimen is imaged onto the camera.

SUMMARY OF THE INVENTION

Methods for using electron diffraction holography to investigate a sample, according to the present disclosure include the initial steps of emitting a plurality of electrons toward the sample, forming the plurality of electrons into a first electron beam and a second electron beam, and then modifying the focal properties of at least one of the first electron beam and the second electron beam such that the two electron beams have different focal planes. Once the two beams have different focal planes, methods according to the present invention include the additional steps of focusing the first electron beam such that it has a focal plane at or near the sample, and focusing the second electron beam so that it is incident on the sample, and has a focal plane in the diffraction plane. An interference pattern of the first electron beam and the diffracted second electron beam is then detected in the diffraction plane, and then used to generate a diffraction holograph.

Systems for investigating a sample using electron holography, according to the present disclosure comprise a sample holder configured to hold a sample, an electron emitter configured to emit electrons towards the sample, and a bifocal beamformer positioned between the electron emitter and the sample holder. The bifocal beamformer is configured to form the plurality of electrons into a first electron beam and a second electron beam, and modify the focal properties of at least one of the first electron beam and the electron particle beam. The modified focal properties of the first electron beam and the second electron enables another component of the system (e.g., a stigmator) to cause the corresponding focal planes of the first electron beam and the second electron beam to be different. In some embodiments, the bifocal beamformer modifies the focal properties of at least one of the beams such that the first electron beam is focused at a plane at or near the sample and the second electron beam is not focused at the plane at or near the sample.

BRIEF DESCRIPTION OF THE DRAWINGS

The detailed description is described with reference to the accompanying figures. In the figures, the left-most digit(s) of a reference number identify the figure in which the reference number first appears. The same reference numbers in different figures indicates similar or identical items.

FIG. **1** illustrates example bifocal multibeam systems for using diffraction holography to investigate a sample according to the present invention.

FIGS. **2**A and **2**B illustrate a first electron beam and a second electron beam interacting with the sample during electron diffraction holography in an example bifocal multibeam system.

FIG. **3** illustrates a sample process for investigating a sample with diffraction electron holography using bifocal multibeam system according to the present invention.

FIGS. **4**, **5**, and **6** are illustrations of the optical performance of a bifocal multibeam systems according to the present invention.

FIG. **7** illustrates example bifocal multibeam systems for investigating a sample where the bifocal beamformer comprises a MEMS device.

FIG. **8** illustrates an example MEMS device according to the present invention.

FIG. **9** illustrates a top down schematic view of an example embodiment of MEMS device that comprises four electrodes.

FIG. **10** illustrates a top down schematic view of an example embodiment of MEMS device that comprises seven electrodes.

FIG. **11** illustrates the distortion of the second electron beam caused when an example embodiment bifocal beamformer causes at least a quadrupole lensing effect to be applied thereto.

FIG. **12** illustrates example embodiments of bifocal multibeam systems for investigating a sample where the bifocal beamformer comprises an aperture lens array.

FIG. **13** illustrates an example electrode for an example aperture lens array.

FIG. **14** illustrates an example aperture defining structure for an example aperture lens array.

FIG. **15** illustrates a cross section of an example aperture lens array having one aperture defining structure.

FIGS. **16-24** illustrate example central structures which can be used in the multiple aperture assembly illustrated in FIG. **23**.

FIG. **25** illustrates a cross section of an example aperture lens array that comprises comprising a first electrode, a second electrode, and an aperture defining structure.

FIG. **26** illustrates example embodiments of bifocal multibeam systems for investigating a sample where the bifocal beamformer comprises a beam splitting mechanism and one or more focusing devices.

Like reference numerals refer to corresponding parts throughout the several views of the drawings. Generally, in the figures, elements that are likely to be included in a given example are illustrated in solid lines, while elements that are optional to a given example are illustrated in broken lines. However, elements that are illustrated in solid lines are not essential to all examples of the present disclosure, and an element shown in solid lines may be omitted from a particular example without departing from the scope of the present disclosure.

DETAILED DESCRIPTION OF EMBODIMENTS

Methods and systems for performing electron diffraction holography, are included herein. More specifically, the methods and systems disclosed herein include and/or are configured to allow for diffraction holograms of a sample to be generated from interference patterns between an in-focus electron beam and a wide reference electron beam that are detected in the diffraction plane. In the methods and systems, a plurality of electrons that have been emitted by an electron source are split into a coherent first and second electron beam, and the focal properties of at least one of the first electron beam and the second electron beam are modified such that corresponding focal planes of the first electron beam and the second electron beam are different. In some embodiments, the focal plane of at least one of the first electron beam and the second electron beam is modified such that the first electron beam is focused at a plane at or near the sample, and the second electron beam is made to be a parallel (or almost parallel), convergent, or divergent beam when incident on the sample. In various embodiments, the first electron beam passes through an aperture in the sample and/or a thin portion of the sample such that it is not substantially affected by the sample, allowing the first electron beam to serve as a reference beam. An interference pattern of the first electron beam and the diffracted second electron beam is then detected in the diffraction plane, and then used to generate a diffraction hologram. The diffraction hologram provides both phase and amplitude of the diffraction pattern.

For example, when the above process is used in micro-electron diffraction, diffraction holograms of a sample (e.g., a crystal) may be obtained at a plurality of sample tilts to determine information for the sample (e.g., phase and amplitude of diffraction peaks). Alternatively, the above processes may be used to generate a single diffraction hologram of a sample (e.g., crystalline, multi-crystalline, partly crystalline, non-crystalline, etc.) from which holographic techniques can be used to determine the full exit wave of the specimen (i.e., a complex exit wave including both phase and amplitude) can be retrieved. If this is repeated to obtain the full exit wave of the specimen at multiple sample tilts then 3D information (i.e., tomography) can be obtained using the above process. In some embodiments, the plurality of electrons are split and/or modified at least partially by a bifocal beamformer. The bifocal beamformers according to some embodiments of the present invention are configured to apply a at least a quadrupole lensing effect to at least one of the first electron beam and the second electron beam. In some embodiments, the bifocal beamformers causes the focal planes of the two electron beams to be different. Alternatively, in some embodiments, the bifocal beamforms causes a change in the focal properties of at least one of the electron beams such that, when the beams are passed through a multipole element (i.e., a multipole/corrector/stigmator that applies at least a quadrupole lensing effect) downstream of the bifocal beamformer, the corresponding focal planes of the two beams are caused to be different. For example, one beam may be caused to have a focal plan at a sample, and the other beam may have a corresponding focal plane at least 0.1%, 1%, 10%, or 100% of the objective lens focal distance above and/or below the specimen. The diameter of one beam at the sample may be at least one of 50, 100, 500, or 1000 times greater than the diameter of the other electron beam (i.e., the geometric spot size). Alternatively, or in addition, the diameter of one beam at the sample may be at least one of 50, 100, 500, or 1000 times greater than the diameter of the other electron beam when the other electron beam is in focus.

FIG. **1** is an illustration of bifocal multibeam system(s) **100** that is set up to conduct diffraction holography, according to the present invention. Specifically, FIG. **1** illustrates an example bifocal multibeam system(s) **102** for using diffraction holography to investigate a sample **104**. The example bifocal multibeam system(s) **102** may include electron microscope (EM) setups or electron lithography setups that are configured to irradiate and/or otherwise impinge the sample **104** with at least two beams of electrons that have different corresponding focal planes. In various embodiments, the bifocal multibeam system(s) **102** may be or include one or more different types of EM and/or charged particle microscopes, such as but not limited to, a scanning electron microscope (SEM), a scanning transmission electron microscope (STEM), a transmission electron microscope (TEM), a charged particle microscope (CPM), dual beam microscopy system, etc. Additionally, in some embodiments, a bifocal multibeam system(s) **102** may be a TEM which is capable of operating as a STEM as well.

The example bifocal multibeam system(s) **102** includes an electron source **106** (e.g., a thermal electron source, Schottky-emission source, field emission source, etc.) that emits a plurality of electrons **108** (i.e., an electron beam) along an emission axis **110** and towards a bifocal beamformer **112**. The emission axis **110** is a central axis that runs along the length of the example bifocal multibeam system(s) **102** from the electron source **106** and through the sample **104**.

The bifocal beamformer **112** is one or more structures configured to (i) split the plurality of electrons **108** into at least a first electron **114** and a beam second electron beam

116, and (ii) modify the focal properties of at least one of the first electron beam **114** and a second electron beam **116**. For example, the bifocal beamformer **112** may modify the focal properties such that the first electron beam **114** and the second electron beam **116** have different corresponding focal planes. FIG. **1** illustrates the bifocal beamformer **112** as splitting the plurality of electrons **108** into a first electron beam **114** that runs along the emission axis **110** and a second electron beam **116**. Because each of the first electron beam **114** and the second electron beam **116** are formed from the plurality of electrons **108**, the first electron beam **114** and a second electron beam **116** are mutually coherent.

FIG. **1** also shows the bifocal beamformer **112** as applying a distortion to the second electron beam **116** that causes the focal properties of the second electron beam to differ from the focal properties of the first electron beam **114**. For example, FIG. **1** illustrates the bifocal beamformer **112** as being configured to generate at least a quadrupole field (i.e. dipole field, quadrupole field, hexapole field, octupole field, etc.) that applies a quadrupole lensing effect that affects the second electron beam **116** such that the two beams have a different focal properties. The at least a quadrupole lensing effect may distort, stigmate, or otherwise modify at least one of the beams such that the corresponding focal properties of the beams are made different. In some embodiments, the quadrupole lensing effect may apply a different lensing effects in one meridional plane (e.g. an x-z plane) than in a perpendicular meridional plane (e.g., a y-z plane), causing a different change to each of the focal properties in each of the two meridional planes. Such a stigmation is illustrated in the example system shown in FIG. **4**.

In such embodiments, a multipole element (e.g., a stigmator) downstream of the bifocal beamformer may apply a complimentary quadrupole lensing effect to the one of the second electron beam **116** to correct for aberrations caused by the bifocal beamformer **112**, and cause the second electron beam **116** to become a cylindrically symmetric beam again. In this way, the multipole element causes the second electron beam **116** to be cylindrically symmetric cylindrically symmetric downstream of such a multipole element while also having different focal planes from the first electron beam **114**. In various setups this multipole element may be placed in a focal plane of the first electron beam **114** so that the complementary quadrupole lensing effect is not applied to the first electron beam **114**.

In some embodiments, the bifocal beamformer **112** is configured to modify the focal properties of at least one of the first electron beam **114** and the second electron beam **116** such that the second electron beam **116** has a focal plane at a specimen plane at or near the sample **104** and the first electron beam **114** has a corresponding focal plane that is not at the specimen plane at or near the sample **104**. In various embodiments, the bifocal beamformer **112** may modify the focal plane of the first electron beam **114** such that it is focused at a plane which is located at least 0.1%, 1%, 10%, or 100% of the objective lens focal distance above or below the sample **104**. Alternatively, the bifocal beamformer **112** may modify the focal properties of at least one of the electron beams such that the first electron beam **114** has a focal plane at a specimen plane at or near the sample **104** and the second electron beam **116** has a corresponding focal plane that is not at the specimen plane at or near the sample **104**. In such embodiments, the focal planes(s) may be modified such that the second electron beam **116** is focused at a plane which is located at least 0.1%, 1%, 10%, or 100% of the objective lens focal distance above and/or below the sample **104**.

While FIG. **1** illustrates an embodiment where one of the beams is focused in the specimen plane (i.e., have a focal plane at or near the specimen plane), a person having skill in the art will understand that bifocal multibeam systems **100** according to the present invention do not require that either of the electron beams be focused in the specimen plane. Moreover, while the bifocal beamformer **112** is shown as modifying the focal properties of the second electron beam **116**, in other embodiments the bifocal beamformer **112** may cause the focal properties of the first electron beam **114**, or both beams to be changed, such that the two beams have different corresponding focal planes. That is, a person having skill in the art would understand that the actions or effects described as being applied to one beam may be applied to the other beam in a different embodiment to enable the two beams to have different corresponding focal planes.

Alternatively or in addition, the bifocal beamformer **112** may be configured to modify the focal properties of at least one of the first electron beam **114** and the second electron beam **116** such that the diameter of the first electron beam **114** at a specimen plane at or near the sample **104** is at least one of 20, 50, 100, 500, or 1000 times greater than the diameter of the second electron beam **116** at the specimen plane. In such embodiments, the bifocal beamformer **112** may cause the diameter of the first electron beam **114** to be at least one of 20, 50, 100, 500, or 1000 times greater than the diameter for the second electron beam **116** at any plane where the second electron beam **116** is in focus. In some embodiments, the bifocal beamformer **112** further causes one or both of the first electron beam **114** and the second electron beam **116** to be deflected away from the emission axis **110**.

In some embodiments, the bifocal beamformer **112** may be composed of a single component that performs both the forming of the first electron beam **114** and the second electron beam **116** and the modification of the focal properties of at least one of the two beams. For example, the bifocal beamformer **112** may correspond to a microelectromechanical system (MEMS) that both forms the two beams and generates at least a quadrupole electromagnetic field (i.e. dipole field, quadrupole field, hexapole field, octupole field, etc.) which applies at least a quadrupole lensing effect that focuses, stigmates, and/or otherwise modifies at least one of the beams such that the corresponding focal properties of the beams are made different. In another example, the bifocal beamformer **112** may correspond to an aperture array comprising a structure defining a plurality of apertures and/or cavities that both form the two beams and create at least a quadrupole electromagnetic fields that applies the quadrupole lensing effect to one or more of the two beams. In some embodiments, the quadrupole lensing effect may apply a positive lensing in one meridional plane (e.g. an x-z plane) and a negative lensing effect in a perpendicular meridional plane (e.g., a y-z plane), causing a different change to each of the focal properties in each of the two meridional planes.

In such systems, a multipole element **124** (e.g., a corrector, a stigmator or a multipole element which is part of an aberration corrector, a corrector of the quadrupole/octupole type, etc.) may be included in the example bifocal multibeam system(s) **100** further downstream to apply a complementary quadrupole lensing effect to make the beam cylindrically symmetric again. For example, FIG. **1** illustrates the bifocal multibeam system(s) **102** as including a stigmator. Alternatively or in addition, the bifocal beamformer **112** may be positioned and/or configured to cause at least one of

the one or more aberrations of the electron beams to correct another aberration in the bifocal multibeam system(s) **102**. Such a system component may be positioned in a focal plane of the electron beam to which bifocal beamformer **112** did not apply at least a quadrupole lensing effect. In embodiments where the bifocal beamformer applies at least a first quadrupole lensing effect to the first electron beam **114** and a second quadrupole lensing effect to the second electron beam **116**, such a bifocal multibeam system(s) **100** may include a first multipole element **124** positioned in a focal plane of the first electron beam **114** and configured to apply a complementary quadrupole lensing effect to the second electron beam **116**, and a second multipole element **124** positioned in a focal plane of the second electron beam **116** and configured to apply a complementary quadrupole lensing effect to the first electron beam **114**.

Alternatively, the bifocal beamformer **112** may be composed of a plurality of components **118**. Individual components **118** may perform one of the forming of the first electron beam **114** and the second electron beam **116** and the modification of the focal properties of at least one of the two beams, or they may contribute to one or both of the forming the beams and modifying of focal properties in concert with other components **118**. In some embodiments, the individual components **118** may include a physical structure that blocks a portion of the plurality of electrons **108** while allowing others to pass through, a biprism (e.g., a charged wire), an amplitude-division electron beam splitter made of thin crystals or nanofabricated gratings, a beam splitting laser system configured to use one or more lasers pattern fringes to split the plurality of electrons **108** into the first electron beam **114** and the second electron beam **116**, etc. Alternatively, or in addition, the individual components **118** may include one or more lenses (e.g., an einzel lens, a quadrupole lens, etc.) that are positioned or otherwise configured to cause the first electron beam **114** and the second electron beam **116** to have different focal planes. For example, the bifocal beamformer **112** may be composed of a physical structure defining two apertures, and a lens positioned and/or configured to adjust the focal properties of the at least one of the first electron beam and the second electron beam such that they have different corresponding focal planes. In various embodiments, such a lens may be positioned above or below the physical structure.

FIG. **1** illustrates the bifocal beamformer **112** as being positioned upstream of focusing component **120** that is configured to apply a lensing action that focuses at least one of the first electron beam **114** and the second electron beam **116**. Moreover, the focusing component **120** is positioned upstream of the multipole element **124**. In the example bifocal multibeam system(s) **102** shown in FIG. **1**, the focusing component corresponds to an accelerator **122** that accelerates/decelerates, focuses, and/or directs the first electron beam **114** and the second electron beam **116** towards a focusing column **126**. However, in other embodiments, the accelerator **122** may be positioned between electron source **106** and the bifocal beamformer **112** such that the accelerator **122** accelerates/decelerates, focuses, and/or directs the electrons **108** to the bifocal beamformer **112**, and the bifocal beamformer **112** splits and modifies the focal properties of electrons **108** at a final energy (e.g., 30 kV). In such embodiments, the focusing component **120** may correspond to a lens or other structure configured to apply a lens action that focuses at least one of the first electron beam **114** and the second electron beam **116**.

The focusing column **126** focuses the electron beams **114** and **116** so that they are incident on sample **104**. Specifically, FIG. **1** illustrates the focusing column **126** focusing the second electron beam **116** so that is focused on the sample **104** and the first electron beam **114** such that it is not focused on the sample **104**. In some embodiments, one of the first electron beam **114** or second electron beam **116** may be parallel, substantially parallel, convergent, or divergent when it is incident on the sample **104**. Moreover, in other embodiments, the focusing column **126** may cause the first electron beam **114** to be focused on the sample **104** and the second electron beam **116** to not be focused on the sample **104**. In other embodiments the focusing column **126** may cause neither beam to be focused at the sample. While not illustrated in FIG. **1**, those having skill in the art will understand focusing column **126** may include one or more correctors (e.g., a Cs or Cs+Cc aberration corrector), transfer lenses, deflectors, scan coils, beam blankers, etc. necessary to enable and/or enhance the investigation of the sample **104** with the bifocal multibeam system(s) **102**.

FIG. **1** also shows the bifocal multibeam system(s) **102** as including an objective lens **128**. The objective lens **128** is an optical element that focuses one of the first electron beam **114** and the second electron beam **116** to a point on the sample **104**. The objective lens **128** may comprise a single-polepiece lens, a magnetic electrostatic compound lens, electrostatic detector objective lens, or another type of objective lens. For example, the objective lens **128** may correspond to a TEM objective lens in which the sample is immersed within the TEM objective lens and/or between the pre-specimen and post specimen components of the TEM objective lens. FIG. **1** further illustrates the bifocal multibeam system(s) **102** as including a sample holder **130** that holds the sample **104**. FIG. **1** shows the first electron beam **114** as being a TEM beam that is incident on the sample **104** and the second electron beam **116** as being a reference beam that passes through an aperture in the sample **104** and/or a thin portion of the sample such that it is not substantially affected by the sample, allowing the second electron beam **116** to serve as a reference beam during electron diffraction holography.

FIG. **1** further shows the bifocal multibeam system(s) **102** as including a detector **132** positioned in the diffraction plane that is configured to detect the second electron beam **116** and the diffracted electrons **134** that pass through the sample **104** as a result of the electron beams **114** being incident on the sample **104**. During electron diffraction holography, the detector **132** is configured to generate an interference pattern of the second electron beam and the diffracted first electron beam in the diffraction plane, and then used to generate a diffraction hologram and/or a hologram image of the sample. Such an embodiment may further include one or more projection lenses **136** positioned between the sample **104** and the detector **132**. In some embodiments, zero-loss filtering may be applied during the generation of the diffraction hologram.

FIG. **1** further shows bifocal multibeam system(s) **102** as optionally including computing device(s) **142**. In various embodiments, the computing device(s) **142** may be configured to determine, based on a known phase of the second electron beam **116** and the interference pattern detected by the detector **132**, a diffraction hologram of the sample **104**. Because the first electron beam **114** and the second electron beam **116** are mutually coherent, the computing devices **142** are able to determine the phase of the electrons diffracted by the sample. This further allows the computing devices **142** to determine both the phase and the amplitude of the diffraction pattern. For example, in micro-electron diffraction, the computing systems may obtain diffraction holo-

grams of a crystal at multiple orientations of the crystal (i.e., sample tilts) to determine the phase and amplitude of the diffraction peaks. Such phase and amplitude information can be used to determine the structure and/or other crystallographic information about the crystal, even where no prior information was known about the crystal. Moreover, in some embodiments, the computing devices **142** are further configured to use the diffraction hologram to retrieve the specimen exit wave function (e.g., both amplitude and phase), and/or use the specimen exit wave function to determine the crystal lattice and/or a hologram image of the sample **104**.

Those skilled in the art will appreciate that the computing devices **142** depicted in FIG. **1** are merely illustrative and are not intended to limit the scope of the present disclosure. The computing system and devices may include any combination of hardware or software that can perform the indicated functions, including computers, network devices, internet appliances, PDAs, wireless phones, controllers, oscilloscopes, amplifiers, etc. The computing devices **142** may also be connected to other devices that are not illustrated, or instead may operate as a stand-alone system.

FIGS. **2**A and **2**B are illustrations of the first electron beam and the second electron beam interacting with the sample during electron diffraction holography in an example bifocal multibeam system **100**.

Specifically, FIG. **2**A illustrates the first electron beam **114** as being a TEM illumination beam that is substantially perpendicular to the sample plane at the sample **104**, and the second electron beam **116** is shown as being a reference beam. However, in other embodiments the second electron beam **116** may act as the TEM illumination beam, and the first electron beam **116** may act as a reference beam. FIG. **2**A shows the reference beam as passing through an aperture **202** in the sample **104**. The aperture **202** may have any shape, such as circular, polynomial, ovoid, slit, etc. In other embodiments, the reference beam may pass through a thin portion of the sample such that it is not substantially affected by the sample. Alternatively, the reference beam may be directed so that it passes by the sample without passing through it. FIG. **2**A shows the first electron beam **114** as being an axial beam, however in other embodiments the first electron beam **114** as being a non-axial beam. Similarly, while FIG. **2**A illustrates the second electron beam **116** as being a non-axial beam, in other embodiments the second electron beam **116** may be an axial beam.

FIG. **2**A further shows the first electron beam **114** as having a front focal plane **204** positioned above the objective lens **130**, and a back focal plane **206** that corresponds to the diffraction plane **208**. FIG. **2**A also illustrates a portion **210** of the first electron beam **114** that is scattered/diffracted by the sample **104**. The detector **132** is positioned so as to detect both the portion **210** of the first electron beam **114** that is scattered/diffracted by the sample **104** and the second electron beam **116** in the diffraction plane **208**. As understood by those in the art, the portion **210** and the second electron beam **116** form an interference pattern based on the structure and/or characteristics of the sample. For example, where the sample is a crystal, the interference pattern may correspond to a plurality of peaks (i.e., Airy disks).

Similarly, FIG. **2**B illustrates an embodiment **250** of the present invention where the TEM illumination beam (shown in FIG. **2**B as the electron beam **116**) is a non-parallel beam at the specimen. Specifically, FIG. **2**B shows a virtual diffraction plane **222** above the sample plane **212**. While FIG. **2**B shows the TEM illumination beam as being a divergent beam at the sample, in other embodiments the TEM illumination beam may be a convergent beam.

In the diffraction plane **208**, the wave function of the diffracted portion **210** of the first electron beam **114** is the Fourier transform of the sample exit wave function. In this way, a pixel in the interference pattern detected in the diffraction plane **208** (i.e., diffraction hologram) corresponds to a spatial frequency in the sample exit wave. Because the two electron beams are mutually coherent, the complex exit wave in the sample plane **212** can be mathematically extracted from the interference pattern detected in the diffraction plane **208**.

FIG. **3** is a flow diagram of illustrative processes illustrated as a collection of blocks in a logical flow graph, which represent a sequence of operations that can be implemented in hardware, software, human operation, or a combination thereof. In the context of software, the blocks represent computer-executable instructions stored on one or more computer-readable storage media that, when executed by one or more processors, cause the performance of the recited operations. Generally, computer-executable instructions include routines, programs, objects, components, data structures, and the like that perform particular functions or implement particular abstract data types. The order in which the operations are described is not intended to be construed as a limitation, and any number of the described blocks can be combined in any order and/or in parallel to implement the processes.

FIG. **3** is a depiction of a sample process **300** for investigation of a sample with diffraction electron holography using bifocal multibeam system(s) **100** according to the present invention. The process **300** may be implemented in any of the example microscope system(s) **100**, **700**, **1200**, and **2400**.

At **302**, a plurality of electrons are emitted towards a sample by an electron source. The electron source may include a thermal electron source, Schottky-emission source, field emission source, etc. The electron source emits the plurality of electrons along an emission axis.

At **304**, the plurality of electrons are formed into a first electron beam and a second electron beam. According to the present invention, the plurality of electrons are formed into the two beams by a bifocal beamformer or a component thereof. In some embodiments, a component of the bifocal beamformer defines at least a first aperture that is configured to allow a first portion of the electrons to pass through the bifocal beamformer (i.e., the first electron beam) and a second aperture configured to allow a second portion of the electrons to pass through the bifocal beamformer (i.e., the second electron beam). Alternatively, or in addition, the bifocal beamformer may include a biprism, an amplitude-division electron beam splitter made of thin crystals or nanofabricated gratings, a beam splitting laser system, or another type of mechanism known to those skilled in the art for splitting electron beams.

At **306**, the focal properties of at least one of the first electron beam and the second electron beam is modified. Specifically, according to the present invention the bifocal beamformer or a component thereof is further configured to modify the focal properties of at least one of the first electron beam and a second electron beam such that the two beams have different corresponding focal planes. In some embodiments, the focal properties and/or focal planes of both beams is adjusted. However, in other embodiments, the focal properties and/or focal planes of just one of the two beams is adjusted.

In some embodiments, the bifocal beamformer is a MEMS device that comprises a plurality of electrodes configured to, when certain voltages are applied thereto,

generate an electromagnetic field pattern that applies at least quadrupole a lensing effect to one of the electron beams. In another example, where the bifocal beamformer comprises a plurality of apertures and/or cavities, the plurality of apertures and/or cavities form a pattern that creates an electromagnetic field that applies at least a quadrupole lensing effect to one of the electron beams during use of the bifocal beamformer. Such lensing effects focus, stigmate, or otherwise modify at least the electron beam such that the corresponding focal properties of the two beams are made different. In some embodiments, a quadrupole lensing effect applied by the bifocal beam former adjusts the focal properties of one of the electron beams while applying an astigmatism to the beam that causes it to be non-cylindrically symmetric (see, FIG. **4**). In such embodiments, a multipole element (e.g., a stigmator) downstream of the bifocal beamformer applies a complimentary quadrupole lensing effect to the one of the electron beams to cause it to become a cylindrically symmetric beam again. Thus, downstream of such a corrector each electron beam may be cylindrically symmetric, while having different focal planes. In various setups this corrector may be placed in a focal plane of the other electron beam so that the quadrupole lensing effect is not applied to the other electron beam.

Alternatively, or in addition, the bifocal beamformer may include one or more lenses positioned or otherwise configured to modify the focal planes of the first or second electron beam. In some embodiments, the bifocal beamformer adjusts the focal properties and/or focal planes of different regions of the electrons emitted by the electron source before they are split into the first and second electron beams, such that when the electrons are split into the two electron beams, the two beams have different corresponding focal planes.

At **308**, one of the electron beams is focused onto a first plane on the sample, and at **310**, the other electron beam is focused on a second plane that is not at or near the sample. In various embodiments, the one of the electron beams is focused so that it passes through an aperture in the sample and/or a portion of the sample that is thin enough that the electron beam is not substantially affected by the sample. This allows the one of the electron beams to serve as a reference beam that enables diffraction electron holography.

In some embodiments, the other electron beam is focused on a plane located at least 0.1%, 1%, 10%, or 100% of the objective lens focal distance above and/or below the sample. Additionally, the two electron beams may be focused such that the diameter of one of the electron beams at the sample is at least one of 50, 100, 500, or 1000 times greater than the diameter of the other electron beam at the sample. In some embodiments, the electron beams pass through a focusing column that directs them onto their respective focus planes. The focusing column may include one or more correctors, transfer lenses, deflectors, scan coils, beam blankers, etc. necessary to enable and/or enhance the investigation of the sample.

At **312**, electrons and/or emissions resultant from the electron beams interacting with the sample are detected. For example, one or more detectors positioned in the diffraction plane may detect portions of the electron beams that are transmitted through the sample, electrons diffracted by the sample, emissions from the sample, or a combination thereof. Specifically, an interference pattern of the two electron beams is detected. In some embodiments, the interfere pattern is detected in the diffraction plane.

At **314**, a diffraction hologram is generated is generated based on the interference pattern of the two electron beams. Because the two beams are mutually coherent, the one of the electron beams has a known phase and acts as a reference beam to enable the phase of the electrons diffracted by the sample, allowing both the phase and the amplitude of the diffraction pattern to be determined. As discussed above, this process can be used to determine the phase and amplitude of the diffraction peaks in the interference pattern/diffraction hologram, which can in turn be used to determine the structure and/or other crystallographic information about the crystal, even where no prior information was known about the crystal.

Moreover, the diffraction hologram can then be used to retrieve the specimen exit wave function (e.g., both amplitude and phase). In some embodiments, this specimen wave function can then be used to determine the crystal lattice (i.e., crystal structure) and/or a hologram image of the sample structure.

In an alternate or supplemental process step, the phase information of the specimen exit wave function may be determined separate from the holography analysis discussed above. For example, where the beam that is focused so that it passes through the sample is applied multiple times with different known relative phase shifts (e.g., by shifting, defocusing, or causing other kinds of aberrations to one of the two beams using, e.g., the bifocal beamforming MEMS device, etc.), the resulting intensity patterns can be recorded and then used to derive the relative phase of the wave at the detector/in the diffraction plane. For example, a phase difference cp between the detected interference pattern/diffraction hologram and the reference beam may be according to the relationships:

$$\tan\varphi = \frac{Ls_b^2 - s_a^2}{Lc_b s_b - c_a s_a};\ L = \frac{I_2 - I_1}{I_3 - I_1};\ s_a = \sin(\alpha/2);\ c_a = \cos(\alpha/2);\ s_b = \sin(\beta/2);\ c_b = \cos(\beta/2); \quad (1)$$

where I_1, I_2, and I_3 are the measured intensities for 3 different phase shifts between the two beams, a is the phase shift difference of one of the beams between a first measurement and a second measurement, and β is the phase shift difference of one of the beams between the first measurement and a third measurement.

FIGS. **4-6** are illustrations of the optical performance of a bifocal multibeam system(s) **100** according to the present invention. FIG. **4** shows example beam paths of example bifocal multibeam system **400** setup to conduct electron diffraction holography. Specifically, FIG. **4** shows beam paths for an example bifocal multibeam system **400** where a quadrupole lensing effect is applied to a non-axial first electron beam **402**, and no quadrupole lensing effect is applied to an axial second electron beam **404**. FIG. **4** shows example beam paths of the axial first electron beam **402** and the non-axial second electron beam **404** in the y-z plane **450**, and the x-z plane **470**.

FIG. **4** depicts an electron source **106** emitting a plurality of electrons **108** toward a bifocal beamformer **112**. The bifocal beamformer **112** is illustrated as both splitting the plurality of electrons **108** into an axial first electron beam **404** and a non-axial second electron beam **402**. FIG. **4** further illustrates the bifocal beamformer **112** as applying at least a quadrupole lensing effect to the non-axial first electron beam **402**, which changes the focal properties of the non-axial first electron beam **402**. FIG. **4** shows how in some embodiments the at least the quadrupole lensing effect

applies a stigmation to the non-axial first electron beam **402**. That is, FIG. **4** illustrates how the quadrupole lensing effect may apply a first lensing effect to the non-axial first electron beam **402** in one meridional plane (i.e., a negative lensing effect in the x-z plane **450**) and a second, different lensing effect to the non-axial first electron beam **402** in a perpendicular meridional plane (i.e., a positive lensing effect in the y-z plane **470**). FIG. **4** shows how these two different lensing effects in different planes cause the non-axial first electron beam **402** to no longer be a cylindrically symmetric beam (i.e., the radius of the beam in the x-z plane is the not same as the radius of the beam in the y-z plane).

FIG. **4** also illustrates the example bifocal multibeam system **400** as including a multipole element **124** that is positioned at a focal plane of the axial second electron beam **404** and is configured to apply at least a quadrupole lensing effect to the non-axial first electron beam **402** such that it is once again a cylindrically symmetric beam (i.e., the radius of the beam in the x-z plane is the same as the radius of the beam in the y-z plane). Because the corrector is positioned in a plane where the axial second electron beam **404** is focused to a point, the effect of the multipole element **124** on the axial second electron beam **404** is minimized. In various embodiments, the column deflectors and/or the tilt of sample holder can be used to tune the tilt and/or shift of the beams with respect to sample, while preserving the mutual tilt angle between the two beams. FIG. **4** further shows the multipole element **124** as generating a dipole electromagnetic field that applies a deflection to each of the first electron beam **402** and the second electron beam **404**. FIG. **4** illustrates this force as causing the first electron beam **402** to become an axial beam downstream of the multipole element **124** and causing the second electron beam **404** to become a non-axial beam downstream of the multipole element **124**.

FIG. **4** shows the first electron beam **402** as being a reference beam that passes through an aperture in the sample **104**, and the second electron beam **404** as being a TEM beam that is incident on the sample **104**. The TEM beam has a front focal plane **406** upstream of the sample **104** and a back focal plane **408** downstream of the sample **104**. The back focal plane **408** corresponds to the diffraction plane **408**. FIG. **4** also shows the objective lens **128** as being a TEM objective lens comprising a pre-specimen component and a post specimen component.

FIG. **5** shows example beam paths of example bifocal multibeam system **500** where a quadrupole lensing effect is applied to an axial first electron beam **502**, and no quadrupole lensing effect is applied to a non-axial second electron beam **504**. Specifically, FIG. **5** shows example beam paths of the axial first electron beam **502** and the non-axial second electron beam **504** in the y-z plane **550**, and the x-z plane **570**.

FIG. **5** depicts an electron source **106** emitting a plurality of electrons **108** toward a bifocal beamformer **112**. The bifocal beamformer **112** is illustrated as both splitting the plurality of electrons **108** into an axial first electron beam **902** and a non-axial second electron beam **904**. FIG. **9** further illustrates the bifocal beamformer **112** as applying at least a quadrupole lensing effect to the axial first electron beam **902**, which changes the focal properties of the axial first electron beam **902**. Specifically, FIG. **5** shows how in some embodiments the at least the quadrupole lensing effect applies a first effect to the axial first electron beam **502** in one meridional plane (i.e., a negative lensing effect in the x-z plane) and a second, different effect to the axial first electron beam **502** in a perpendicular meridional plane (i.e., a positive lensing effect in the y-z plane).

FIG. **5** also illustrates the example bifocal multibeam system **500** as including a multipole element **124** that is positioned at a focal plane of the non-axial second electron beam **504** and is configured to apply at least a quadrupole lensing effect to the axial first electron beam **502** such that it is once again a cylindrically symmetric beam. Because the corrector is positioned in a plane where the non-axial second electron beam **504** is focused to a point, the effect of the corrector on the non-axial second electron beam **504** is minimized. In various embodiments, the column deflectors and/or the tilt of sample holder can be used to tune the tilt of the electron beams with respect to sample, while preserving the mutual tilt angle between the two beams. In various embodiments, column deflectors and/or the tilt of a sample holder can be used to tune the tilt of the electron beams with respect to sample, while preserving the mutual tilt angle between the two beams.

FIG. **6** shows example beam paths of bifocal multibeam system **600** where at least a quadrupole lensing effect is applied to a non-axial reference electron beam **602** and an axial electron TEM beam **604**. FIG. **6** depicts an electron source **106** emitting a plurality of electrons **108** toward a bifocal beamformer **112**. The bifocal beamformer **112** is illustrated as both splitting the plurality of electron **108** into a non-axial reference electron beam **602** and an axial electron TEM beam **604**. FIG. **6** further illustrates the bifocal beamformer **112** as applying at least a quadrupole lensing effect to the non-axial reference electron beam **602**, which changes the focal properties of the non-axial reference electron beam **602**.

In some embodiments, a result of the quadrupole lensing effect is that the non-axial reference electron beam **602** is no longer a cylindrically symmetric beam. A multipole element **124** (e.g., a multipole, a stigmator, etc.) for correcting one or more astigmatisms and/or causing the non-axial reference electron beam **602** to be cylindrically symmetric is shown in FIG. **1** as being positioned at a focal plane of the axial electron TEM beam **604**. For example, the multipole element **124** may apply at least a quadrupole lensing effect to the non-axial reference electron beam **602** such that it becomes cylindrically symmetric again. Because the corrector is positioned in a plane where the axial reference electron beam **602** is focused to a point, the effect of the corrector on the beam is minimized.

The focusing column **126** is shown as including a hexapole corrector **606**. In the depicted embodiment, the hexapoles **608** of the hexapole corrector **606** are shown as being positioned at focal planes of the axial electron TEM beam **604**. The focusing column **126** is shown as focusing the non-axial reference electron beam **602** onto a specimen focal plane **612**. To illustrate this, FIG. **6** depicts an inset **610** that shows a focal plane **614** of the on-axial reference electron beam **602** as coinciding with the specimen focal plane **612**. The inset **610** further shows that the focusing column **126** as focusing the axial electron TEM beam **604** such that it has a focal plane **616** upstream of the specimen focal plane **612** and a focal plane **618** downstream of the specimen focal plane **614**.

FIG. **7** is an illustration of an example embodiment **700** of bifocal multibeam system(s) **100** for investigating a sample **104** where the bifocal beamformer comprises a MEMS device **702**.

The example bifocal multibeam system(s) **700** includes an electron source **106** that emits a plurality of electrons **108** along an emission axis **110** and towards an accelerator **120**. The accelerator **120** accelerates/decelerates, focuses, and/or directs the first electron beam **114** and the second electron

beam **116** towards a bifocal beamformer **112**. FIG. **7** illustrates the accelerator **120** as being positioned upstream of bifocal beamformer **112**, as discussed above, in other embodiments the bifocal beamformer **112** may be positioned between the electron source **106** and the accelerator **120**.

In example bifocal multibeam system(s) **700**, the bifocal beamformer **112** corresponds to a MEMS device **702**. The MEMS device **702** defines a first aperture and a second aperture that are each configured to allow a portion of the plurality of electrons **108** to pass through the MEMS device **702**. In this way, the first aperture and the second aperture split the plurality of electrons **108** into the first electron beam **114** and the second electron beam **116**, respectively. FIG. **7** illustrates the first electron beam **114** as being an axial beam.

The MEMS device **702** further comprises a plurality of electrodes that are configured such that, when certain voltages are applied thereto, the electrodes generate a quadrupole electromagnetic field that applies at least a quadrupole lensing effect (i.e., dipole field, quadrupole field, hexapole field, octupole field, etc.) to the second electron beam **116**. The quadrupole lensing effect focuses, stigmatizes, or otherwise modifies at least the second electron beam **116** such that the corresponding focal properties of the beams are made different. In some embodiments, the electrodes are configured such that the first electron beam **114** is not affected by the electromagnetic field generated by the electrodes and/or such an effect is reduced. Alternatively, or in addition, a portion of the electrodes may generate an electromagnetic field that applies a different lensing effect to the first electron beam **114** and the second electron beam **116**.

FIG. **7** illustrates the MEMS device **702** as being positioned upstream of focusing component **120** that is configured to apply a lensing action that focuses at least one of the first electron beam **114** and the second electron beam **116**. In the example bifocal multibeam system(s) **700** shown in FIG. **7**, the focusing component corresponds to lens **120** that focuses, and/or directs the first electron beam **114** and the second electron beam **116** towards a focusing column **126**. However, in other embodiments the accelerator **122** may be positioned between electron source **106** and the MEMS device **702**, and the accelerator **122** may replace or augment the lens **704** (as illustrated in FIG. **1**).

The focusing column **126** and the objective lens **128** focus the electron beams **114** and **116** so that they are incident on sample **104**. Specifically, FIG. **7** illustrates the focusing column **126** focusing the second electron beam **116** so that is focused on the sample **104** and the first electron beam **114** such that it is not focused on the sample **104**. FIG. **7** shows the second electron beam **116** as being a reference beam that passes through a thin portion of the sample **104**, and the first electron beam **114** as being a TEM beam that is incident on the sample **104**.

In some embodiments, the focal planes the first electron beam **114** and the second electron beam **116** are modified such that one of the beams is focused at a plane at or near the sample **104** and the other electron beam is focused at a plane which is located at least 0.1%, 1%, 10%, or 100% of the objective lens focal distance above and/or below the sample **104**. Alternatively or in addition, the focal planes of the first electron beam **114** and the second electron beam **116** may be modified such that the diameter of one of the electron beams at the sample **104** is at least one of 5, 10, 20, 50, 100, 500, or 1000 times greater than the diameter of the other electron beam at the sample.

FIG. **8** shows a cross section of an example embodiment **800** of MEMS device **700** according to the present invention. Specifically, FIG. **8** illustrates a cross section of a MEMS device **700** configured to split a plurality of electrons **802** into the first electron beam **804** and the second electron beam **806**, and generate an electromagnetic field pattern that applies at least a quadrupole lensing effect to the second electron beam **806**. The at least the quadrupole lensing effect causes the first electron beam **804** and the second electron beam **806** to have different focal properties. For example, the quadrupole lensing effect may apply a positive lensing effect in one meridional plane (e.g. an y-z plane) and a negative lensing effect in a perpendicular meridional plane (e.g., a x-z plane), causing a different change to the focal properties in each of the two meridional planes. In such embodiments, another system component (e.g., a corrector or stigmator) may be included downstream of the bifocal beamformer **700** to apply another quadrupole lensing effect to make the beam cylindrically symmetric again.

FIG. **8** illustrates MEMS device **700** as including a surface layer **808**, an electrode layer **810**, and an optional shielding layer **812**. In FIG. **8**, the surface layer **808** is shown as comprising a thin material (e.g., a foil) upon which the electrons **802** are incident. However, a person having skill in the art would understand that in other embodiments, the surface layer **808** may not be a correspond to separate component layer, but rather correspond to an upper surface of one or more components of the MEMS device **700** upon which the electrons **802** are incident.

The surface layer **808** defines a first entrance **814** to a first aperture **816** and a second entrance **818** to a second aperture **820**. In some embodiments, the first aperture **814** is an axial aperture (i.e., positioned on the emission axis of the electrons **802**) and the second aperture **818** is a non-axial aperture. In such embodiments, the first electron beam **804** is an axial beam. The first entrance **814** allows a first portion of the electrons **802** (i.e., the first electron beam **804**) to pass into the first aperture **816** and through the MEMS device **700**. Similarly, the second entrance **818** allows a second portion of the electrons **402** (i.e., the second electron beam **806**) to pass into the second aperture **820** and through the MEMS device **700**. The surface layer **808** inhibits the ability of the remaining portions of electrons **802** to pass into and/or through the MEMS device **700**.

The electrode layer **810** comprises a plurality of microelectrodes that are shaped, positioned, or otherwise configured such that when corresponding voltages are applied to the one or more electrodes, the one or more electrode generate electromagnetic field patterns that apply a lensing effect to one or both of the first electron beam **804** and the second electron beam **806**. The lensing effect is such that the focal properties of the two beams are modified such that they have different corresponding focal properties. One or more of the magnitude of the voltages applied to the electrodes, the shape of the electrodes, and the thickness (L) of the electrodes can be modified to change the strength of the generated electromagnetic field patterns. According to the present invention, the electrodes in the electrode layer **810** are configured such that they generate at least a quadrupole electromagnetic field pattern applies at least a quadrupole lensing effect (i.e., dipole field, quadrupole field, hexapole field, octupole field, etc.) to the second electron beam **806**. In some embodiments, the electromagnetic field pattern may also apply dipole fields to one or both of the first electron beam **804** and the second electron beam **806**. Such dipole fields may cause at least one of the electron beams to be deflected in a direction perpendicular to the emission axis.

FIG. **8** also illustrates the MEMS device **700** as including an optional shielding layer **812** that is opposite the surface layer **808**, and which is configured to at least partially

insulate the first electron beam **814** from the at least quadrupole lensing effects applied to the second electron beam **816**.

FIG. **9** shows top down schematic view of an example embodiment **900** of MEMS device **700** that comprises four electrodes. FIGS. **9** and **10** illustrate in solid lines the first entrance **814** and second entrance **818** as defined by surface layer **808** in solid lines. Additionally, FIGS. **9** and **10** illustrate the components of the electrode layer **810** in dashed lines. A person having skill in the art would recognize that the dashed lines do not represent the exact shape, but rather indicate general outlines electrodes in the electrode layer **810**.

FIG. **9** shows the radius R_{A1} of the first entrance **814** as being lesser than the radius R_{E1} of the first aperture as at least partially defined by electrode **902**. In an embodiment of example MEMS device **900**, the radius R_{A1} may be at or around 10 μm and the radius R_{E1} may be at or around 14 μm or greater. The radius R_{A2} of the second entrance **818** is shown in FIG. **9** as being lesser than the radius R_{E2} of the second aperture as at least partially defined by electrodes **902**, **904**, **906**, and **908**. However, in other embodiments one or both of radius R_{E1} and radius R_{A1} and/or radius R_{E2} and radius R_{A2} may be the same. The example embodiment **900** is further shown as having the radius R_{A1} and the radius R_{A2} as being equal and/or approximately equal, however this is not required for all embodiments. The first entrance **814** and the second entrance **818** are separated by the distance D.

During use of the example MEMS device **900**, voltages may be applied to one or more of the electrodes **902-908** such that the electrodes generate an electromagnetic field that applies at least a quadrupole lensing effect to the second electron beam. In some embodiments, one or more of the electrodes may be grounded. For example, the example MEMS device **900** may generate an electromagnetic field that applies at least a quadrupole lensing effect to the second electron beam when a first voltage **V1** is applied the electrode **904**, a second voltage **V2** is applied to electrode **908**, and electrodes **902** and **906** are grounded. In various embodiments, **V1** and **V2** may each be greater than −20V and less than 20V, however larger voltages can also be used.

FIG. **10** shows top down schematic view of an example embodiment **1000** of MEMS device **700** that comprises seven electrodes. FIG. **10** shows the radius R_{A1} of the first entrance **814** as being lesser than the radius R_{E1} of the first aperture as at least partially defined by electrodes **1002**, **1004**, **1006**, and **1008**. FIG. **10** illustrates the first aperture **814** as being an axial aperture through which the emission axis **1010** of the plurality of electrons passes.

The radius R_{A2} of the second entrance **818** is also shown in FIG. **10** as being lesser than the radius R_{E2} of the second aperture as at least partially defined by electrodes **1006**, **1012**, **1014**, and **1016**. However, in other embodiments one or both of radius R_{E1} and radius R_{A1} and/or radius R_{E2} and radius R_{A2} may be the same.

During use of the example MEMS device **1000**, voltages may be applied to one or more of the electrodes **1002-1008** and **1012-1016** such that the electrodes generate an electromagnetic field that applies at least a quadrupole lensing effect to the second electron beam. In some embodiments, one or more of the electrodes may be grounded. For example, the example MEMS device **1000** may generate an electromagnetic field that applies at least a quadrupole lensing effect to the second electron beam when a first set of voltages between the values of −20V and 20V are applied to electrodes **1004**, **1008**, **1012**, and **1016**, a second set of voltages between the values of −5V and 5V is applied to electrodes **1002** and **1014**, and electrode **1006** is grounded.

Additionally, a person having skill in the art would understand that the dashed lines in FIGS. **9** and **10** represent example configurations of electrodes, and that experimentation would provide multiple electrode configurations (e.g., electrode size, electrode shape, quantity of electrodes, layout of electrodes, combination of voltages applied to electrodes, etc.) that cause the electrodes to generate an electromagnetic field that applies at least a quadrupole lensing effect to the second electron beam. Moreover, while each of FIGS. **5** and **6** illustrate an embodiment where the at least quadrupole lensing effect is applied to the second electron beam, in other embodiments the electrode layer may be configured to generate an electromagnetic field that applies at least a quadrupole lensing effect to the first electron beam (or both electron beams) when a corresponding set of voltages are applied to the electrodes.

FIG. **11** is an illustration **1100** of the change in focal properties of the second electron beam caused when an example embodiment bifocal beamformer causes at least a quadrupole lensing effect to be applied thereto. Specifically, FIG. **11** shows an emitter **1102** emitting a plurality of electrons **1104** along an emission axis **1106**. The plurality of electrons **1104** strike the bifocal beamformer **1108** in a circular area **1110**. The bifocal beamformer **1108** is shown in FIG. **11** as being a MEMS device that (i) defines a first aperture **1112** and a second aperture **1114** that split the electron beam **1104** into a first electron beam **1116** and a second electron beam **1118**, respectively, and (ii) generates an electromagnetic field that applies at least a quadrupole lensing effect to the second electron beam **1118** when in use.

As illustrated in FIG. **11**, in some embodiments the at least a quadrupole lensing effect causes the second electron beam **1118** to be distorted such that it (i) has a different focal properties from the first electron beam **1116**, and (ii) is no longer a cylindrically symmetric beam. Specifically, FIG. **11** shows the cross-sectional areas of the first electron beam **1116** and the second electron beam **1118** in an plane **1120** downstream of the bifocal beamformer **1108**, where the emission axis is normal to the plane **1120**. The first electron beam **1116** is shown as having a circular (or near circular) cross section **1122** when it crosses the plane **1120**, and the second electron beam **1118** is shown as having a non-circular cross section **1124** when it crosses the plane **1120**. Applicant notes that these cross sections are not illustrative of the performance of all embodiments of bifocal beamformers according to the present invention, but are limited to the specific example embodiment of bifocal beamformer **1108**.

FIG. **12** is an illustration of an example embodiment **1200** of bifocal multibeam system(s) **100** for investigating a sample **104** where the bifocal beamformer comprises an aperture lens array **1203**.

The example bifocal multibeam system(s) **1202** includes an electron source **106** that emits a plurality of electrons **108** along an emission axis **110** and towards an aperture lens array **1204**. The aperture lens array **1204** comprises at least one aperture defining structure **1206** that defines (i) a first aperture that allows the first electron beam **114** to pass through the at least one aperture defining structure **1206**, (ii) a second aperture that allows the second electron beam **116** to pass through the at least one aperture defining structure **1206**, and (iii) plurality of other apertures. The first aperture, the second aperture, and the plurality of apertures collectively form a pattern that, when a voltage(s) is applied to the aperture defining structure **1206** and the electrode(s) **1208**,

creates an electromagnetic field that applies a lensing effect (e.g., at least a quadrupole lensing effect) to at least one of the first electron beam **114** and the second electron beam **116**. The lensing effect distorts one or both of the first electron beam **114** and the second electron beam **116** such that they have different focal properties.

The aperture lens array **1204** further comprises one or more electrodes (e.g., disk electrodes) **1208**. The each of the one or more electrodes **1208** generate an electric field between the corresponding electrode and the at least one aperture defining structure **1206** when a voltage is supplied thereto. Additionally, in some embodiments, one or more of the electrodes **1208** may physically block a portion of the plurality of electrons **108** from reaching the at least one aperture defining structure **106**. For example, one of the electrodes **1208** may define a first aperture that allows a first portion of electrons to pass through the electrode (i.e., a first electron beam) and a second aperture that allows a second portion of electrons to pass through the electrode (i.e., a second electron beam).

FIG. **12** illustrates the bifocal beamformer **112** as being positioned upstream of focusing component **120** that is configured to apply a lensing action that focuses at least one of the first electron beam **114** and the second electron beam **116**. In the example bifocal multibeam system(s) **1202** shown in FIG. **12**, the focusing component corresponds to an accelerator **122** that accelerates/decelerates, focuses, and/or directs the first electron beam **114** and the second electron beam **116** towards a focusing column **126**.

The focusing column **126** and the objective lens **128** focus the electron beams **114** and **116** so that they are incident on sample **104**. Specifically, FIG. **12** illustrates the focusing column **126** focusing the second electron beam **116** so that is focused on a plane at or near the sample **104** and the first electron beam **114** such that it is not focused at the plane at or near the sample **104**. In some embodiments, the focal properties of the first electron beam **114** and the second electron beam **116** are modified such that one of the beams is focused at a plane at or near the sample **104** and the other electron beam is focused at a plane which is located at least 0.1%, 1%, 10%, or 100% of the objective lens focal distance above and/or below the sample **104**. Alternatively or in addition, the focal properties the first electron beam **114** and the second electron beam **116** may be modified such that the diameter of one of the electron beams at the sample **104** is at least one of 50, 100, 500, or 1000 times greater than the diameter of the other electron beam at the sample.

FIG. **13** illustrates an example **1300** electrode **1202** for an example aperture lens array **1204**. The electrode **1208** is shown in FIG. **13** as being a disk electrode **1302** that defines an aperture **1304** that allows electrons to pass through the disk electrode **1302**.

FIG. **14** illustrates an example **1400** aperture defining structure **1402** for an example aperture lens array **1204**. The example aperture defining structure **1402** defines (i) a first aperture **1404** that allows a first electron beam to pass through the at least one aperture defining structure **1402**, (ii) a second aperture **1406** that allows a second electron beam to pass through the at least one aperture defining structure **1402**, and (iii) plurality of other apertures **1408**. In the example embodiment shown in FIG. **14**, each of the first aperture **1404**, the second aperture **1406**, and three apertures **1408** are positioned along a midline **1410** of the aperture defining structure **1402**.

FIG. **14** illustrates each of the plurality of other apertures **1408** as being holes that allow electrons to pass through the aperture defining structure **1402**. However, in other embodiments one or more of the apertures **1408** may be cavities where the aperture defining structure **1402** defines an empty space into which electrons are allowed to enter, but which do not allow the electrons to pass through the aperture defining structure. The first aperture **1404**, the second aperture **1406**, and the plurality of apertures **1408** collectively form a pattern that induces an electromagnetic field that applies a lensing effect (e.g., at least a quadrupole lensing effect) to at least the second electron beam.

FIG. **15** illustrates a cross section of an example aperture lens array **1500** having one aperture defining structure. Specifically, FIG. **15** shows a cross section of an example aperture lens array **1500** comprising the example electrode **1302** of FIG. **13** and the example aperture structure **1402** of FIG. **14**, where the cut of the cross section aligns with the midline **1410** of the example aperture structure **1402**.

FIG. **15** shows electrons **1502** being emitted along an emission axis toward the electrode **1302**. A portion of the electrons **1502** pass through both the aperture **1304** and the first aperture **1404**, becoming first electron beam **1506**. Another portion of the electrons **1502** pass through both the aperture **1304** and the second aperture **1406**, becoming second electron beam **1508**. In some embodiments, the aperture lens array **1500** includes a second electrode positioned such that the at least one aperture defining structure **1402** is between the two electrodes. When voltages are applied to the electrode **1302**(A), the electrode **1302**(B), both electrodes **1302**(A) and **1302**(B), and/or the aperture defining structure **1402**, electromagnetic fields are created between the electrodes **1302** and the aperture defining structure **1402**. While FIG. **15** illustrates the aperture lens array **1500** as comprising two electrodes, in some embodiments the aperture lens array **1500** may only include one electrode (either electrodes **1302**(A) or **1302**(B)).

The aperture lens array **1500** is configured such that the configuration of the electrodes **1302** (i.e., one electrode, both electrodes, the positions of such electrodes, the geometry of such electrodes, etc.), the voltages (or lack of voltages) applied to individual ones of the electrodes **1302** and the aperture defining structure **1402**, and the pattern that the first aperture **1404**, the second aperture **1406**, and the plurality of apertures **1408** collectively create an electromagnet field that creates a first lensing effect on the first electron beam and a second lensing effect on the second electron beam, where the first and second lensing effects are different. For example, in an embodiment of the present invention, the electromagnetic field may create a lensing effect (e.g., at least a quadrupole lensing effect) that causes the first electron beam **1506** and the second electron beam **1508** to have different focal properties.

In some embodiments, the electromagnetic field also deflects one or both of the first electron beam **1506** and the second electron beam **1508** away from the emission axis **1504**. Also, while FIG. **15** illustrates the first electron beam **1508** as an axial beam that travels along the emission axis **1504** of the plurality of electrons **1502**, this is not required in all embodiments.

FIGS. **16-24** show example central structures which can be used in the multiple aperture assembly **2500** illustrated in FIG. **25**. Specifically, FIG. **16** illustrates an example aperture defining structure **1600** for an example aperture lens array that includes a combination of holes and cavities. The example aperture defining structure **1602** defines (i) a first aperture **1604** that allows a first electron beam to pass through the at least one aperture defining structure **1602**, (ii) a second aperture **1606** that allows a second electron beam to pass through the at least one aperture defining structure

1602, and (iii) plurality of other apertures **1608**. The first aperture **1604**, the second aperture **1606**, and the plurality of apertures **1608** collectively form a pattern that induces an electromagnetic field that applies a lensing effect (e.g., at least a quadrupole lensing effect) to at least the second electron beam when voltages are applied to at least the aperture defining structure **1600** and electrodes **2504** and **2512** during use of the multiple aperture assembly **2500**. In some embodiments, the aperture lens structure **1602** comprises a single physical component that defines each of the first aperture **1604**, the second aperture **1606**, and the plurality of apertures **1608**. However, in other embodiments the aperture lens structure **1602** may comprise two or more component physical structures.

FIG. **16** illustrates an example embodiment in which five of the plurality of other apertures **1608** correspond to holes **1610**, and four of the plurality of other apertures **1608** correspond to cavities **1612**. However, in other embodiments the plurality of other apertures **1608** may comprise other combinations and/or patterns of holes and cavities, including embodiments where all of the plurality of other apertures **1608** correspond to one of holes (e.g., the aperture defining structure illustrated in FIG. **14**) or cavities, exclusively. In the example embodiment shown in FIG. **16**, each of the first aperture **1604**, the second aperture **1606**, and two other apertures **1608** are positioned along a line **1614** of the aperture defining structure **1602**.

FIG. **17** illustrates a cross section **1700** of example aperture structure **1602** that comprises a single physical structure **1702**. Specifically, FIG. **17** shows a cross section of an embodiment of the example aperture structure **1602** of FIG. **16**, with the cut of the cross section aligning with the line **1614**. A first portion of the electrons **1704** are allowed to pass through the physical structure **1702** via holes **1706**. FIG. **17** further shows a second portion of the electrons **1704** are allowed to pass into cavities **1708** that prevent them from passing through the physical structure **1702**.

FIG. **18** illustrates a cross section **1800** of example aperture structure **1602** that comprises a first physical structure **1802** and a second physical structure **1804**. Specifically, FIG. **18** shows a cross section of an embodiment of the example aperture structure **1602** where it is comprised of two structures (e.g., foils), with the cut of the cross section aligning with the line **1614**. FIG. **18** illustrates holes **1806** in the example aperture structure **1602** as corresponding to complementary apertures in the first physical structure **1802** and a second physical structure **1804** that together allow a first portion of the electrons **1808** to pass through the aperture structure **1602**. FIG. **18** also illustrates cavities **1810** as corresponding to apertures in the first physical structure **1802** that do not have a complimentary aperture in the second physical structure **1804**. In other words, the cavities **1810** are configured such that a second portion of the electrons **1808** is allowed to pass into a space **1812** between the first physical structure **1802** and the second physical structure **1804**, but are not allowed to pass through the aperture structure **1602**.

FIGS. **19** and **20** illustrate a pair of component physical structures that can be used to form an aperture defining structure **2306** in the aperture lens array **2500** illustrated in FIG. **25**. Specifically, FIG. **19** illustrates an example first component physical structure **1900** of an example aperture defining structure comprising two physical structures. The example first component physical structure **1900** defines (i) a first aperture **1904** that allows a first electron beam to pass through the first component physical structure **1900**, (ii) a second aperture **1906** that allows a second electron beam to pass through first component physical structure **1900**, and (iii) plurality of other apertures **1908**. Each of these apertures are illustrated as having a rectangular geometry (e.g., a long slot). Such rectangular apertures are configured to create a cylindrical lensing effect on electrons passing through them during use of the example aperture defining structure. In the example embodiment shown in FIG. **19**, each of the first aperture **1904**, the second aperture **1906**, and two apertures **1908** are positioned along a midline **1910** of the first component physical structure **1900**.

FIG. **20** illustrates an example second component physical structure **2000** of an example aperture defining structure comprising two physical structures. The example second component physical structure **2000** defines (i) a first aperture **2004** that allows a first electron beam to pass through the second component physical structure **2000**, (ii) a second aperture **2006** that allows a second electron beam to pass through second component physical structure **2000**, and (iii) plurality of other apertures **2008**. Apertures **2004** and **2008** are shown as having a rectangular geometry, similar to the apertures defined by the first component physical structure **1900** illustrated in FIG. **19**. The second aperture **2006** is illustrated in FIG. **20** as combining both a rectangular geometry and a circular geometry. In other words, the second aperture **2006** is shown as being a circular aperture centrally positioned and overlaid with an aperture having a rectangular geometry. This combination of the geometry of the second aperture **1906** and the second aperture **2006** cause a net quadrupole lensing effect to be applied to the electron beam B as it passes through the second apertures **1906** and **2006**. Similarly, the geometries of the first aperture **1904** and the first aperture **2004** cause a no net lensing effect to be applied to the electron beam A. In the example embodiment shown in FIG. **20**, each of the first aperture **2004**, the second aperture **2006**, and two apertures **2008** are positioned along a midline **2010**.

FIGS. **21** and **20** illustrate a pair of component physical structures that can be used to form an aperture defining structure **2306** in the aperture lens array **2500** illustrated in FIG. **25**. Specifically, FIG. **21** illustrates an example first component physical structure **2100** of an example aperture defining structure comprising two physical structures. The example first component physical structure **2100** defines (i) a first aperture **2104** that allows a first electron beam to pass through the first component physical structure **2100**, (ii) a second aperture **2106** that allows a second electron beam to pass through first component physical structure **2100**, and (iii) plurality of other apertures **2108**. Such apertures are configured to create a quadrupole lensing effect on electrons passing through the second aperture **2106** during use of the example aperture defining structure. In the example embodiment shown in FIG. **21**, each of the first aperture **2104**, the second aperture **2106**, and other apertures **2108** are positioned along a midline **2110** of the first component physical structure **2100**.

FIG. **22** illustrates an example second component physical structure **2200** of an example aperture defining structure comprising two physical structures. The example second component physical structure **2200** defines (i) a first aperture **2204** that allows a first electron beam to pass through the second component physical structure **2200**, (ii) a second aperture **2206** that allows a second electron beam to pass through second component physical structure **2200**, and (iii) plurality of other apertures **2208**. Apertures **2204** and **2208** are shown as having a geometry similar to the apertures defined by the first component physical structure **2200** illustrated in FIG. **22**. The combination of the geometry of

the second aperture **2106** and the second aperture **2206** causes no net lensing effect to be applied to the electron beam A. Similarly, the geometries of the first aperture **2104** and the first aperture **2204** cause a net quadrupole lensing effect to be applied to the electron beam B as it passes through the second apertures **2106** and **2206**. In the example embodiment shown in FIG. **22**, each of the first aperture **2204**, the second aperture **2206**, and two apertures **2028** are positioned along a midline **2210**.

FIGS. **23** and **24** illustrate a pair of component physical structures that can be used to form an aperture defining structure **2506** in the aperture lens array **2500** illustrated in FIG. **25**. Specifically, FIG. **23** illustrates an example first component physical structure **2300** of an example aperture defining structure comprising two physical structures. The example first component physical structure **2300** defines (i) a first aperture **2304** that allows a first electron beam to pass through the first component physical structure **2300**, (ii) a second aperture **2306** that allows a second electron beam to pass through first component physical structure **2300**, and (iii) plurality of other apertures **2308**. Each of these apertures are illustrated as having a rectangular geometry (e.g., a long slot). Such rectangular apertures are configured to create a cylindrical lensing effect on electrons passing through them during use of the example aperture defining structure. In the example embodiment shown in FIG. **23**, each of the first aperture **2304**, the second aperture **2306**, and two apertures **2308** are positioned along a midline **2310** of the first component physical structure **2300**.

FIG. **24** illustrates an example second component physical structure **2400** of an example aperture defining structure comprising two physical structures. The example second component physical structure **2400** defines (i) a first aperture **2404** that allows a first electron beam to pass through the second component physical structure **2400**, (ii) a second aperture **2406** that allows a second electron beam to pass through second component physical structure **2400**, and (iii) plurality of other apertures **2408**. Apertures **2404** and **2408** are shown as having a rectangular similar to the apertures defined by the first component physical structure **2300** illustrated in FIG. **23**. This combination of the geometry of the second aperture **2306** and the second aperture **2406** causes no net lensing effect to be applied to the electron beam A. Similarly, the geometries of the first aperture **2304** and the first aperture **2404** cause a net quadrupole lensing effect to be applied to the electron beam B that passes through the second apertures **2306** and **2406**. In the example embodiment shown in FIG. **24**, each of the first aperture **2404**, the second aperture **2406**, and two apertures **2408** are positioned along a midline **2410**.

FIG. **25** illustrates a cross section of an example aperture lens array **2500** comprising a first electrode **2502**, a second electrode **2504**, and an aperture defining structure **2506**. FIG. **25** shows electrons **2508** being emitted toward a first electrode **2502**. The first electrode **2502** is shown as defining a pair of apertures **2512** that allow a portion of the electrons **2508** to pass through the first electrode **2502**. In some embodiments, the first electrode **2502** may correspond to an electrically conductive foil that defines the two apertures **2512**. A first portion of the electrons **2508** pass through both a first aperture becoming first electron beam **2514**. Another portion of the electrons **2508** pass through both the second aperture becoming second electron beam **2516**.

In all embodiments, the aperture lens array **2500** includes a second electrode **2504** positioned such that the aperture defining structure **2506** is between the two electrodes. The second electrode **2504** may correspond to a disk electrode defining an aperture **2518** that allows the first electron beam **2514** and the second electron beam **2516** pass through the second electrode **2504**.

When certain voltages are applied to both the electrodes **2502** and **2504**, and/or aperture defining structure **2506**, electromagnetic fields are created between the electrodes **2502** and **2504**. The electromagnetic fields and the pattern that the apertures defined by the aperture defining structure **2506** collectively create a lensing effect that causes the first electron beam **2514** and the second electron beam **2516** to have different focal planes.

While non-limiting, a simple representative calculation can be used to illustrate the performance of some embodiments of the present invention having different array patterns for the upstream and downstream components (e.g., the embodiment depicted in FIGS. **19** and **20**, the embodiment depicted in FIGS. **21** and **22**, the embodiment depicted in FIGS. **23** and **24**). To enable this simple representative calculation, the following paragraphs assume that (a) $|\phi_0(z)| \ll U$ everywhere, (b) the field component $E_z = -\phi_0'(z)$ close to the aperture array plates changes from E_{up} (i.e., the nonzero electric field above the aperture defining structure **2506**) to 0 in above the aperture defining structure **2306**, (c) the field component $E_z = -\phi_0'(z)$ close to the aperture array plates changes from 0 to E_{low} (i.e., the nonzero electric field below the aperture defining structure **2506**) below the aperture defining structure **2506**, and (d) the field between the array plates is a zero field (e.g. the plates in FIGS. **19** and **20**).

In the simple representative calculation, the electrostatic potential up to order 2 in the x and y direction can be generally expressed as:

$$\phi(x,y,z) = U + \phi_0(z) + p\phi_0''(z)x^2 + q\phi_0''(z)y^2 + \phi_2(z)(x^2 - y^2), \tag{2}$$

for an electrostatic potential that is mirror symmetric in the x-z plane and the y-z plane. In expression (1), U represents the electron energy above the aperture lens array **2500**, and the other terms are induced by the voltages applied to both the electrodes **2502** and **2504**, and/or aperture defining structure **2506**. The Laplace equation ($\Delta\phi = 0$) for this electrostatic potential dictates that $p+q=-1/2$. In some examples, this corresponds to $p=q=-1/4$ for a round aperture lens, and $p=-1/2$ and $q=0$ for a cylinder lens which focuses in the x-z plane (such as the embodiment depicted in FIG. **19**).

According to the simple representative calculation, the upstream component of the aperture defining structure **2506** invokes lens strengths:

$$\kappa_{x,up} + f_{x,up}^{-1} = U^{-1}(-p_{up}E_{up} - Q_{up}); \text{ and } \kappa_{y,up} = f_{y,up}^{-1} = U^{-1}(-q_{up}E_{up} + Q_{up}); \tag{3}$$

Similarly, the downstream component of the aperture defining structure **2506** invokes lens strength:

$$\kappa_{x,low} = f_{x,low}^{-1} = U^{-1}(p_{low}E_{low} - Q_{low}); \text{ and } \kappa_{y,low} = f_{y,low}^{-1} = U^{-1}(q_{low}E_{low} + Q_{low}); \tag{4}$$

In these equations, f_x and f_y are the focal distances in the x-z plane and the y-z plane, respectively, and $U^{-1}Q_{up}$ and $U^{-1}Q_{low}$ are the quadrupole lens strengths induced by the quadrupole potential $\phi_2(Z)(x^2 - y^2)$.

In some preferred embodiments, $E_{up} = E_{low} = E$. In such embodiments, the total lens strengths simplify to:

$$\kappa_x = \kappa_{x,up} + \kappa_{x,low} = U^{-1}(p_{low} - p_{up})E - Q); \text{ and} \tag{5}$$

$$\kappa_y = \kappa_{y,up} K_{y,low} = U^{-1}(q_{low} - q_{up})E + Q). \tag{6}$$

Because $p_{up} + q_{up} = p_{low} + q_{low} = -1/2$, it follows that $\kappa_y = -\kappa_x$ in such embodiments, meaning that there is only a pure quadrupole lens action.

In embodiments of aperture lens array **2100** where the electromagnetic field is the same on both sides of the physical structures **1900** and **2000**, the lensing effects caused by the first electron beam **2108** traveling through the first aperture **1904** are canceled and/or otherwise negated by the lensing effects caused by the first electron beam **2108** traveling through the first aperture **2004**. Additionally, in such an embodiment, the lensing effects caused by the second electron beam **2110** traveling through the second aperture **1906** and the lensing effects caused by the second electron beam **2110** traveling through the second aperture **2006** combine to form at least a quadrupole lensing effect.

FIG. **26** is an illustration of an example embodiment **2600** of bifocal multibeam electron system(s) **100** for investigating a sample **104** where the bifocal beamformer **112** comprises a beamsplitting mechanism **2604** and one or more focusing devices **2606**.

The example bifocal multibeam electron system(s) **2602** includes an electron source **106** that emits a plurality of electrons **108** along an emission axis **110** and towards the bifocal beamformer **112**. In the illustrated embodiment of the present invention, the bifocal beamformer **112** is shown as comprising at least (i) a beamsplitting mechanism **2604** that splits the plurality of electrons **108** into the first electron beam **114** and the second electron beam **116**, and (ii) one or more focusing devices **2606** configured to modify the focal properties of one or both of the electron beams such that the two beams do not have the same corresponding focal planes. In some embodiments, the one or more focusing devices **2606** are further configured to cause one or both of the first electron beam **114** and the second electron beam **116** to be deflected away from the emission axis **110**.

In FIG. **26**, the beamsplitting mechanism **2604** is shown as corresponding to a physical structure that defines a first aperture that allows the first electron beam **114** to pass through the beamsplitting mechanism **2604**, and a second aperture that allows the second electron beam **116** to pass through the beamsplitting mechanism **2604**. FIG. **26** further illustrates the one or more focusing devices **2606** as optionally corresponding to two lenses. However, in other embodiments the focusing devices **2606** may correspond to three or more lenses, a single lens that modifies only one of the electron beams, a single lens with a high degree of aberration such that the two electron beams that pass through the lens. Additionally, while FIG. **26** illustrates the beamsplitting mechanism **2604** as being upstream of the one or more focusing devices **2606**, in other embodiments of example bifocal multibeam electron systems **2602** the beamsplitting mechanism **2604** may be downstream of the one or more focusing devices **2606**. Alternatively, in some embodiment some of the focusing devices **2606** may be upstream of the beamsplitting mechanism **2604**, while others of the focusing devices **2606** may be downstream of the beamsplitting mechanism **2604**.

FIG. **26** illustrates the bifocal beamformer **112** as being positioned upstream of focusing component **120** that is configured to apply a lensing action that focuses at least one of the first electron beam **114** and the second electron beam **116**. In the example bifocal multibeam electron system(s) **2602** shown in FIG. **26**, the focusing component corresponds to an accelerator **122** that accelerates/decelerates, focuses, and/or directs the first electron beam **114** and the second electron beam **116** towards a focusing column **126**.

The focusing column **126** and the objective lens **128** focus the electron beams **114** and **116** so that they are incident on sample **104**. Specifically, FIG. **26** illustrates the focusing column **126** focusing the second electron beam **116** so that is focused on the sample **104** and the first electron beam **114** such that it is not focused on the sample **104**. In some embodiments, the focal properties the first electron beam **114** and the second electron beam **116** are modified such that one of the beams is focused at a plane at or near the sample **104** and the other electron beam is focused at a plane which is located at least 0.1%, 1%, 10%, or 100% of the objective lens focal distance above or below the sample **104**. Alternatively or in addition, the focal properties of the first electron beam **114** and the second electron beam **116** may be modified such that the diameter of one of the electron beams at the sample **104** is at least one of 50, 100, 500, or 1000 times greater than the diameter of the other electron beam at the sample.

Examples of inventive subject matter according to the present disclosure are described in the following enumerated paragraphs.

A1. A method for investigating a sample, the method comprising emitting a plurality of charged particles toward the sample; forming the plurality of charged particles into a first charged particle beam and a second charged particle beam; modifying the focal properties of at least one of the first charged particle beam and the second charged particle beam.

A1.1. The method of paragraph A1, wherein modifying the focal properties of at least one of the first charged particle beam and the second charged particle beam comprises modifying one or more of the first charged particle beam and the second charged particle beams such that: the first charged particle beam has a first focal plane; and the second charged particle beam has a second focal plane that is different from the first focal plane.

A1.1.1. The method of paragraph A1.1, wherein modifying the focal properties of at least one of the first charged particle beam and the second charged particle beam comprises modifying one or more of the first charged particle beam and the second charged particle beams such that: the first charged particle beam has a focal plane at a plane at or near the sample; and the second charged particle beam does not have a focal plane at the plane at or near the sample.

A1.1.2. The method of paragraph A1.1, wherein modifying the focal properties of at least one of the first charged particle beam and the second charged particle beam comprises modifying one or more of the first charged particle beam and the second charged particle beams such that: the second charged particle beam has a focal plane at a plane at or near the sample; and the first charged particle beam does not have a focal plane at the plane at or near the sample.

A1.2. The method of any of paragraphs A1-A1.1.2, wherein modifying the focal properties of at least one of the first charged particle beam and the second charged particle beam comprises applying a round lens action to one of the first charged particle beam and the second charged particle beam.

A1.2.1. The method of paragraph A1.2, wherein modifying the focal properties of at least one of the first charged particle beam and the second charged particle beam comprises applying the round lens action to both of the first charged particle beam and the second charged particle beam.

A1.2.1.1. The method of paragraph A1.2.1, wherein the round lens action applied to the first charged particle beam is different from the round lens action applied to the second charged particle beam.

A1.3. The method of any of paragraphs A1-A1.2.1.1, wherein modifying the focal properties of at least one of the first charged particle beam and the second charged particle

beam comprises applying at least a quadrupole lens action to one of the first charged particle beam and the second charged particle beam.

A1.4. The method of any of paragraphs A1-A1.3, wherein the first charged particle beam is an axial beam that travels along on an emission axis of the plurality of charged particles, and the second charged particle beam is a non-axial beam.

A1.5. The method of any of paragraphs A1-A1.4, wherein the second charged particle beam is an axial beam that travels along on an emission axis of the plurality of charged particles, and the first charged particle beam is a non-axial beam.

A2. The method of any of paragraphs A1-A1.5, wherein the charged particles are electrons and the charged particle beams are electron beams.

A3. The method of any of paragraphs A1-A2, wherein a second beam diameter of the second charged particle beam at the sample is at least one of 5, 10, 20, 50, 100, 500, or 1000 times greater than a first beam diameter of the first charged particle beam at the sample.

A3.1. The method of paragraph A3, wherein the second beam diameter is at least one of 5, 10, 20, 50, 100, 500, or 1000 times greater than a first beam diameter at or proximate to each crossover point of the first charged particle beam.

A4. The method of any of paragraphs A1-A3.1, wherein the first charged particle beam is tilted with respect to the second charged particle beam at the sample.

A5. The method of any of paragraphs A1-A4, wherein the first charged particle beam and the second charged particle beam are coherent beams.

A6. The method of any of paragraphs A1-A5, further comprising accelerating each of the first charged particle beam and the second charged particle beam to a final energy with an accelerator.

A7. The method of any of paragraphs A1-A5, further comprising accelerating the plurality of charged particles to a final energy with an accelerator.

A8. The method of any of paragraphs A1-A7, wherein each of the forming the plurality of charged particles and the modifying of the focal properties is performed by a bifocal beamformer.

A8.1. The method of paragraph A8 when dependent from A6, wherein the bifocal beamformer is located above an accelerator.

A8.2. The method of paragraph A8 when dependent from A7, wherein the bifocal beamformer is located below an accelerator.

A8.3. The method of any of paragraphs A8-A8.2, wherein the bifocal beamformer distorts the second charged particle beam.

A8.4. The method of any of paragraphs A8-A8.3, wherein the bifocal beamformer changes the focal planes of the second charged particle beam.

A8.5. The method of any of paragraphs A8-A8.4, wherein the bifocal beamformer causes the second charged particle beam to not be a cylindrically symmetric beam.

A8.5.1. The method of paragraph A8.5, further comprising causing the second charged particle beam to be a cylindrically symmetric beam with a stigmator.

A8.6. The method of any of A8-A8.5.1, wherein the bifocal beamformer causes the second charged particle beam to have one or more aberrations.

A8.6.1. The method of paragraphs A8.6, wherein at least one of the one or more aberrations is a deterministic aberration.

A8.6.2. The method of any of paragraphs A8.6-8.6.1, wherein the bifocal beamformer is positioned and/or configured to cause at least one of the one or more aberrations to correct another aberration in the system.

A8.7. The method of any of paragraphs A8-A8.6.2, wherein the bifocal beamformer is further configured to deflect at least one of the first charged particle beam and the second charged particle beam away from an emission axis of the plurality of charged particles.

A9. The method of any of paragraphs A8-A8.7, wherein the bifocal beamformer comprises a MEMS device configured to generate at least a quadrupole lensing effect that at least partially causes the modifying of the focal properties of at least one of the first charged particle beam and the second charged particle beam.

A9.1. The method of paragraph A9, wherein the MEMS device comprises a structure defining a first aperture and a second aperture, and wherein the first charged particle beam passes through the first aperture and the second charged particle beam passes through the second aperture.

A9.1.1. The method of paragraph A9.1, wherein the first aperture has the same radius as the second aperture.

A9.1.2. The method of paragraph A9.1, wherein the first aperture has a smaller radius than the second aperture.

A9.1.3. The method of paragraph A9.1, wherein the first aperture has a greater radius than the second aperture.

A9.1.4. The method of any of paragraphs A9.1-A9.1.3, wherein the MEMS device comprises a surface layer facing the plurality of charged particles, and wherein the first aperture and the second aperture are defined by the surface layer.

A9.1.4.1. The method of paragraph A9.1.4, wherein the surface layer is a foil.

A9.1.5. The method of any of paragraphs A9.1-A9.1.4.1, wherein the first aperture is an axial aperture positioned on an emission axis of the plurality of charged particles, and the second aperture is a non-axial aperture.

A9.1.6. The method of any of paragraphs A9.1-A9.1.4.1, wherein the second aperture is an axial aperture positioned on an emission axis of the plurality of charged particles, and the first aperture is a non-axial aperture.

A9.2. The method of any of paragraphs A9-A9.1.5, wherein the MEMS device comprises one or more electrodes.

A9.2.1. The method of paragraph A9.2, wherein when corresponding voltages are applied to the one or more electrodes, the one or more electrode generates an electromagnetic field that at least partially applies the at least the quadrupole lensing effect.

A9.2.1. The method of any of paragraphs A9.2-A9.2.1, wherein at least one of the one or more electrodes is grounded.

A9.2.2. The method of any of paragraphs A9.2-A9.2.1 when dependent from A9.1.4, wherein the MEMS device comprises an insulating layer that is opposite the surface layer.

A9.2.2.1. The method of paragraph A9.2.2, wherein the one or more electrodes are located in an electrode layer positioned between the insulating layer and the surface layer.

A9.2.3. The method of any of paragraphs A9.2-A9.2.2.1 wherein the one or more electrodes comprise four electrodes.

A9.2.4. The method of any of paragraphs A9.2-A9.2.2.1 wherein the one or more electrodes comprise seven electrodes.

A9.3. The method of any of paragraphs A9-A9.2.4, wherein the at least the quadrupole lensing effect is one of a dipole lensing effect, quadrupole lensing effect, hexapole lensing effect, and octupole lensing effect.

A9.4. The method of any of paragraphs A9-A9.3, wherein the at least the quadrupole field does not cause the focal plane of the first charged particle beam to be changed.

A9.5. The method of any of paragraphs A9-A9.4, wherein the MEMS device is further configured to generate one or more dipole fields.

A9.5.1. The method of paragraph A9.5, wherein the one or more dipole fields cause at least one of the charged particle beams to be deflected in a direction perpendicular to the emission axis.

A9.6. The method of any of paragraphs A9-A9.5.1, wherein the quadrupole lensing effect applies: a positive lens effect to the first charged particle beam in a first meridional plane of the first charged particle beam; and a negative lensing effect to the first charged particle beam in a second meridional plane of the first charged particle beam, wherein the first meridional plane is perpendicular to the second meridional plane.

A9.6.1. The method of paragraph A9.6, wherein a first change of the focal plane of the first charged particle beam in the first meridional plane caused by the quadrupole field is different than a second change of the focal plane of the first charged particle beam in the second meridional plane caused by the quadrupole field.

A9.7. The method of any of paragraphs A9-A9.5.1, wherein the quadrupole lensing effect applies: a positive lens effect to the second charged particle beam in a first meridional plane of the second charged particle beam; and a negative lensing effect to the second charged particle beam in a second meridional plane of the second charged particle beam, wherein the first meridional plane is perpendicular to the second meridional plane.

A9.7.1. The method of paragraph A9.7, wherein a first change of the focal plane of the second charged particle beam in the first meridional plane caused by the quadrupole field is different than a second change of the focal plane of the second charged particle beam in the second meridional plane caused by the quadrupole field.

A10. The method of any of paragraphs A8-A8.6.2, wherein the bifocal beamformer comprises: a physical structure defining a first aperture and a second aperture, wherein the first charged particle beam passes through the first aperture and the second charged particle beam passes through the second aperture; and a lens positioned and/or configured to adjust the focal properties of the at least one of the first charged particle beam and the second charged particle beam such that they have different focal planes.

A10.1. The method of paragraph A10, wherein the first charged particle beam passes through the first aperture and the second charged particle beam passes through the second aperture.

A10.2. The method of any of paragraphs A10-A10.1, wherein the lens is an einzel lens.

A10.3. The method of any of paragraphs A10-A10.2, wherein the lens is positioned above the physical structure.

A10.4. The method of any of paragraphs A10-A10.2, wherein the lens is positioned below above the physical structure.

A10.5. The method of any of paragraphs A10-A10.4, wherein the lens is positioned and/or configured to adjust the focal planes of the second charged particle beam.

A10.5.1. The method of paragraph A10.5, wherein the lens is not positioned and/or configured to adjust the focal planes of the first charged particle beam.

A11. The method of any of paragraphs A6-A6.5, wherein the bifocal beamformer comprises at least one physical structure that defines: a first aperture that allows the first charged particle beam to pass through the at least one physical structure; a second aperture that allows the second charged particle beam to pass through the at least one physical structure; and plurality of other apertures.

A11.1. The method of paragraph A11, wherein the first aperture, the second aperture, and the plurality of other apertures form a pattern that creates an electromagnetic field that applies a lensing effect to the second charged particle beam during use of the bifocal beamformer.

A11.1.1. The method of paragraph A11.1, wherein the first aperture, the second aperture, and the plurality of other apertures form a pattern that creates an electromagnetic field that applies at least a quadrupole lensing effect to the second charged particle beam during use of the bifocal beamformer.

A11.1.1.1. The method of paragraph A11.1.1, wherein the electromagnetic field does not apply the quadrupole lensing effect to the first charged particle beam during use of the bifocal beamformer.

A11.1.2. The method of any of paragraphs A11.1-A11.1.1.1, wherein the first aperture, the second aperture, and the plurality of other apertures form a pattern that creates an electromagnetic field that applies a circular lensing effect to the first charged particle beam during use of the bifocal beamformer.

A11.1.2.1. The method of paragraph A11.1.2, wherein the plurality of other apertures form a pattern that creates an electromagnetic field that applies at least a circular lensing effect to the second charged particle beam during use of the bifocal beamformer.

A11.1.3. The method of any of paragraphs A11.1-A11.2.1, wherein the lensing effect applied by the electromagnetic field at least partially causes the modifying of the focal properties of at least one of the first charged particle beam and the second charged particle beam.

A11.1.3.1. The method of paragraph A11.1.3, wherein the electromagnetic field does change the focal properties of the first charged particle beam.

A11.3. The method of any of paragraphs A11-A11.2.1, wherein at least one aperture of the plurality of apertures is a hole.

A11.3.1. The method of paragraph A11.3, wherein the hole comprises:

an entrance defined in a first surface of the at least one physical structure, the first surface facing the plurality of charged particles; an exit defined in a second surface of the at least one physical structure that is opposite the first surface; and an empty volume that connects the entrance and the exit.

A11.3.1.1. The method of paragraph A11.3.1, wherein the first surface and the second surface are each surfaces of a single physical structure.

A11.3.1.2. The method of paragraph A11.3.1, wherein the first surface and the second surface are each surfaces of a different physical structures.

A11.4. The method of any of paragraphs A11-A11.3.1.2, wherein at least one aperture of the plurality of apertures is a cavity.

A11.4.1. The method of paragraph A11.4, wherein the cavity comprises: an entrance defined in a first surface of the at least one physical structure, the first surface facing the plurality of charged particles; and an empty volume in

communication with the entrance and defined by the at least one physical structure, wherein the at least one physical structure defines the empty volume such that a charged particle of the plurality of charged particles that enters the empty volume via the entrance does not pass through the bifocal beamformer.

A11.4.1.1. The method of paragraph A11.4.1, wherein the cavity is defined by a single physical structure.

A11.4.1.2. The method of paragraph A11.4.1, wherein the cavity is defined by multiple physical structures.

A11.5. The method of any of paragraphs A11.3-A11.4.1.2, wherein the plurality of apertures comprises a combination of holes and cavities.

A11.6. The method of any of paragraphs A11-A11.5, wherein the geometry of at least one of the first aperture, the second aperture, or an aperture of the plurality of apertures is circular.

A11.7. The method of any of paragraphs A11-A11.5, wherein the geometry of at least one of the first aperture, the second aperture, or an aperture of the plurality of apertures is rectangular.

A11.7.1. The method of any of paragraphs A11-A11.5, wherein the geometry of at least one of the first aperture, the second aperture, or an aperture of the plurality of apertures is a square.

A11.7.2. The method of any of paragraphs A11-A11.5, wherein the geometry of at least one of the first aperture, the second aperture, or an aperture of the plurality of apertures has rounded corners.

A11.8. The method of any of paragraphs A11-A11.7.2, wherein the geometries of the first aperture, the second aperture, and the plurality of apertures is not uniform.

A11.9. The method of any of paragraphs A11-A11.8, wherein the sizes of the first aperture, the second aperture, and the plurality of apertures is not uniform.

A11.10. The method of any of paragraphs A11-A11.9, wherein the bifocal beamformer further comprises a first electrode configured to receive a first applied voltage.

A11.10.1. The method of paragraph A11.10, wherein the first electrode comprises a physical structure that at least partially defines an electrode entrance aperture that allows at least a portion of the plurality of charged particles to pass through the first electrode.

A11.10.1.1. The method of paragraph A11.10.1, wherein the electrode entrance aperture is a first electrode entrance aperture that allows a first portion of the plurality of charged particles to pass through the first electrode, and the second electrode further defines a second electrode entrance aperture that allows a second portion of the plurality of charged particles to pass through the first electrode.

A11.10.2. The method of any of paragraphs A11.10-A11.10.1.1, wherein the first electrode is upstream of the first aperture, the second aperture, and the plurality of apertures.

A11.10.3. The method of any of paragraphs A11.10-A11.10.2, wherein the first electrode is a disk shaped electrode.

A11.10.4. The method of any of paragraphs A11.10-A11.10.2, wherein the bifocal beamformer further comprises a second electrode configured to receive a second applied voltage.

A11.10.4.1. The method of paragraph A11.10.4, wherein the first voltage is different from the second voltage.

A11.10.4.2. The method of paragraph A11.10.4, wherein the first voltage and the second voltage are different.

A11.10.4.3. The method of any of paragraphs A11.10.4-A11.10.4.2, wherein the second electrode comprises a physical structure that at least partially defines an electrode exit aperture that at least one of the first charged particle beam and the second charged particle beam to pass through the second electrode.

A11.10.4.3.1. The method of paragraph A11.10.4.3, wherein the electrode exit aperture is a first electrode exit aperture that allows the first charged particle beam to pass through the second electrode, and the second electrode further comprises a second electrode exit aperture that allows the second charged particle beam to pass through the second electrode.

A11.10.4.3. The method of any of paragraphs A11.10.4-A11.10.4.3.1, wherein the second electrode is positioned downstream of the first aperture, the second aperture, and the plurality of apertures.

A12. The method of any of paragraphs A8-A8.6.2, wherein the bifocal beamformer comprises a biprism that defines a hole, and which is positioned and/or configured to split the plurality of charged particles into the first charged particle beam and the second charged particle beam.

A13. The method of any of paragraphs A8-A8.6.2, wherein laser pattern fringes are used to split the plurality of charged particles into the first charged particle beam and the second charged particle beam.

A14. The method of any of paragraphs A1-A13, wherein the second charged particle beam is focused at a different plane located above the sample.

A13.1. The method of paragraph A13, wherein the different plane is located at least 0.1%, 1%, 10%, or 100% of the objective lens focal distance above the sample.

A14. The method of any of paragraphs A1-A13, wherein the second charged particle beam is focused at a different plane located below the sample.

A14.1. The method of paragraph A14, wherein the different plane is located at least at least 0.1%, 1%, 10%, or 100% of the objective lens focal distance below the sample.

A15. The method of any of paragraphs A13-A14.1, wherein the distance between the plane at or near the sample and the different plane is at least 0.1%, 1%, 10%, or 100% of the objective lens focal distance.

A16. The method of any of paragraphs A1-A15, wherein the second charged particle beam is a parallel beam at the sample.

A17. The method of any of paragraphs A1-A15, wherein the second charged particle beam is a convergent beam at the sample.

A18. The method of any of paragraphs A1-A15, wherein the second charged particle beam is a divergent beam at the sample.

B1. A method for using electron holography to investigate a sample, the method comprising emitting a plurality of electrons toward the sample; forming the plurality of electrons into a first electron beam and a second electron beam; modifying the focal properties of at least one of the first electron beam and the second electron beam such that the two electron beams have different focal planes; focusing the first electron beam such that it has a focal plane at or near the sample; focusing the second electron beam so that it is incident on the sample, and has a focal plane in the diffraction plane; and detecting an interference pattern of the first electron beam and the diffracted second electron beam in the diffraction plane.

B1.1. The method of paragraph B1, further comprising generating a hologram image of the sample based on the interference pattern of the first electron beam and the diffracted second electron beam in the diffraction plane.

B1.2. The method of any of paragraphs B1-B1.1, further comprising determining the phase of electrons diffracted by the sample based on the interference pattern of the first electron beam and the diffracted second electron beam in the diffraction plane.

B1.3. The method of any of paragraphs B1-B1.2, further comprising determining the exit wave function of the electrons leaving the sample in response to the second electron beam being incident on the sample.

B1.3.1. The method of paragraph B1.3, where determining the exit wave function comprises determining the phase and amplitude of the exit wave function of the electrons leaving the sample in response to the second electron beam being incident on the sample.

B1.3.2. The method of any of paragraphs B1.3-B1.3.1, further comprising determining the structure of the sample based on the exit wave function.

B1.3.2.1. The method of paragraph B1.3.2, wherein the sample is a crystal, and determining the structure of the sample comprises determining the crystal lattice of the sample based on the exit wave function.

B1.4. The method of any of paragraphs B1-B1.3.2.1, wherein the method is repeated at a plurality of sample tilts to obtain a plurality of diffraction holograms, each diffraction hologram of the plurality of diffraction holograms corresponding to a sample tilt of the plurality of sample tilts.

B1.4.1. The method of paragraph B1.4, further comprising determining the crystal structure of the sample based on the plurality of diffraction holograms.

B1.5. The method of any of paragraphs B1-B1.4.1, further comprising determining the phase and amplitude of the diffraction peaks of the interference pattern.

B1.5.1. The method of paragraph B1.5, further comprising determining the crystal structure of the sample based at least in part on the phase and amplitude of the diffraction peaks of the interference pattern.

B1.6. The method of any of paragraphs B1-B1.5.51, further comprising: applying a phase shift to the first electron beam; detecting an additional interference pattern of the phase shifted first electron beam and the diffracted second electron beam in the diffraction plane; and determining a phase of the wave function of a sample exit wave in the diffraction plane based at least in part on the interference pattern and the additional interference pattern, wherein the sample exit wave is resultant from the second electron beam being incident on the sample.

B1.6.1. The method of paragraph B1.6, further comprising further comprising: applying a second phase shift to the first electron beam; detecting a second additional interference pattern of the second phase shifted first electron beam and the diffracted second electron beam in the diffraction plane; and the determination of the phase of the wave function of a sample exit wave in the diffraction plane is based at least in part on the second additional interference pattern.

B2. The method of any of paragraphs B1-B1.5.1, wherein one of the first electron beam and the second electron beam is an axial beam that travels along an emission axis of the plurality of charged particles.

B3. The method of any of paragraphs B1-B2, wherein the diffraction plane corresponds to the first focal plane of the second electron beam downstream of the sample.

B4. The method of any of paragraphs B1-B3, wherein the first electron beam and the second electron beam are coherent.

B4. The method of any of paragraphs B1-B3, wherein the first electron plane passes through an aperture in the sample.

B4.1. The method of paragraph B4, wherein the method further comprises, burning the aperture in the sample with one of an electron beam and an ion beam.

B5. The method of any of paragraphs B1-B3, wherein the first electron beam passes through a thin region of the sample such that there is insufficient scattering to disturb the first electron beam.

B6. The method of any of paragraphs B1-B5, wherein the second electron beam is a parallel beam at the sample.

B6.1. The method of any of paragraphs B1-B5, wherein the second electron beam is a convergent beam at the sample.

B6.2. The method of any of paragraphs B1-B5, wherein the second electron beam is a divergent beam at the sample.

B7. The method of any of paragraphs B1-B6, wherein a second diameter of the second electron beam is greater than 5, 10, 20, 50, and 100 times larger than a first diameter of the first electron beam.

B8. The method of any of paragraphs B1-B7, wherein the first charged particle beam is an axial beam that travels along an emission axis of the plurality of charged particles, and the second charged particle beam is a non-axial beam.

B9. The method of any of paragraphs B1-B7, wherein the second charged particle beam is an axial beam that travels along on an emission axis of the plurality of charged particles, and the first charged particle beam is a non-axial beam.

B10. The method of any of paragraphs B1-B9, wherein modifying the focal properties of at least one of the first electron beam and the second electron beam comprises applying a round lens action to one of the first electron beam and the second electron beam.

B10.1. The method of paragraph B10, wherein modifying the focal properties of at least one of the first electron beam and the second electron beam comprises applying the round lens action to both of the first electron beam and the electron particle beam.

B10.1.1. The method of paragraph B10.1, wherein the round lens action applied to the first electron beam is different from the round lens action applied to the second electron beam.

B11. The method of any of paragraphs B1-B10.1.1, wherein modifying the focal properties of at least one of the first electron beam and the second electron beam comprises applying at least a quadrupole lens action to one of the first electron beam and the second electron beam.

B11.1. The method of paragraph B11, wherein the at least a quadrupole lens action applies an astigmatism to the one of the first electron beam and the second electron beam such that it is no longer a cylindrically symmetric beam.

B11.2. The method of any of paragraphs B11-B11.1, wherein the method further comprises, applying an additional at least a quadrupole lensing effect to the one of the first electron beam and the second electron beam.

B11.2.1. The method of paragraph B11.2, wherein the additional at least a quadrupole lensing effect causes the one of the first electron beam and the second electron beam to be a cylindrically symmetric beam.

B11.2.2. The method of any of paragraphs B11.2-B11.2.1, wherein the at least a quadrupole lensing effect is applied by a corrector.

B11.2.2.1. The method of paragraph B11.2.2, wherein the corrector further applies a deflection perpendicular to an emission axis of the plurality of electrons.

B11.2.2.1.1. The method of paragraph B11.2.2.1, wherein the second electron beam is an axial beam, and the deflection causes the second electron beam to be a non-axial beam downstream of the corrector.

B11.2.2.1.2. The method of paragraph B11.2.2.1, wherein the second electron beam is a non-axial beam, and the deflection causes the second electron beam to be an axial beam downstream of the corrector.

B11.2.2.1.3. The method of paragraph B11.2.2.1, wherein the first electron beam is an axial beam, and the deflection causes the first electron beam to be a non-axial beam downstream of the corrector.

B11.2.2.1.4. The method of paragraph B11.2.2.1, wherein the first electron beam is a non-axial beam, and the deflection causes the first electron beam to be an axial beam downstream of the corrector.

B11.2.2.2. The method of any of paragraphs B11.2.2.1-B11.2.2.1.4, wherein the corrector is positioned at a focal plane of the electron beam that did not receive the at least the quadrupole lensing effect.

B12. The method of any of paragraphs B1-B11.2.2.2, wherein the plurality of electrons are split and the first electron beam and the second electron beam are modified by a MEMS device.

B12.1. The method of paragraph B12, wherein the MEMS device comprises a MEMS device of any of paragraphs F1-F12.1.

B13. The method of any of paragraphs B1-B12, wherein the plurality of electrons are split and the first electron beam and the second electron beam are modified by a multi aperture device.

B13.1. The method of paragraph B13, wherein the MEMS device comprises a MEMS device of any of paragraphs F1-F12.1.

B14. The method of any of paragraphs B1-B13, wherein the sample is a crystal.

B14.1. The method of paragraph B14, wherein the diffraction peaks in the diffraction image are Airy disks.

B15. The method of any of paragraphs B1-B14.1, wherein the electrons scattered by the sample have a focal plane in the diffraction plane.

C1. A system for investigating a sample, the system comprising: a sample holder configured to hold a sample; a charged particle emitter configured to emit charged particles towards the sample; a bifocal beamformer positioned between the charged particle emitter and the sample holder, wherein the bifocal beamformer is configured to: form the plurality of charged particles into a first charged particle beam and a second charged particle beam; and modify the focal properties of at least one of the first charged particle beam and the second charged particle beam such that the first charged particle beam is focused at a plane at or near the sample and the second charged particle beam is not focused at the plane at or near the sample.

C2. The system of paragraph C1, wherein the charged particle emitter is an electron emitter configured to emit electrons toward the sample, and the charged particle beams are electron beams.

C3. The system of any of paragraphs C1-C2, wherein a second beam diameter of the second charged particle beam at the sample is at least one of 5, 10, 20, 50, 100, 500, or 1000 times greater than a first beam diameter of the first charged particle beam at the sample.

C3.1. The system of paragraph C3, wherein the second beam diameter is at least one of 5, 10, 20, 50, 100, 500, or 1000 times greater than a first beam diameter at or proximate to each crossover point of the first charged particle beam.

C4. The system of any of paragraphs C1-C3.1, wherein the first charged particle beam is tilted with respect to the second charged particle beam at the sample.

C5. The system of any of paragraphs C1-C4, wherein the first charged particle beam and the second charged particle beam are coherent beams.

C6. The system of any of paragraphs C1-C5, further comprising an accelerator.

C6.1. The system of paragraph C6, wherein the accelerator is positioned below the bifocal beamformer and configured to accelerate each of the first charged particle beam and the second charged particle beam to a final energy.

C6.2. The system of paragraph C6, wherein the accelerator is positioned above the bifocal beamformer and configured to accelerate the plurality of charged particles to a final energy.

C7. The system of any of paragraphs C1-C6.2, wherein the bifocal beamformer distorts the second charged particle beam.

C8. The system of any of paragraphs C1-C7, wherein the bifocal beamformer changes the focal planes of the second charged particle beam.

C9. The system of any of paragraphs C8-C8.4, wherein the bifocal beamformer causes one of the first charged particle beam and the second charged particle beam to not be a cylindrically symmetric beam.

C9.1. The system of paragraph C9, further comprising a corrector configured to cause the second charged particle beam to be a cylindrically symmetric beam.

C9.1.1. The system of paragraph C9.1., wherein the corrector is a stigmator.

C10. The system of any of C1-C9.1.1, wherein the bifocal beamformer causes the second charged particle beam to have one or more aberrations.

C10.1. The system of paragraphs C10, wherein at least one of the one or more aberrations is a deterministic aberration.

C10.2. The system of any of paragraphs C10-C10.1, wherein the bifocal beamformer is positioned and/or configured to cause at least one of the one or more aberrations to correct another aberration in the system.

C11. The system of any of paragraphs C1-C10.2, wherein the bifocal beamformer is further configured to deflect at least one of the first charged particle beam and the second charged particle beam away from an emission axis of the plurality of charged particles.

C12. The system of any of paragraphs C1-C11, wherein the bifocal beamformer comprises a MEMS device configured to generate at least a quadrupole field that at least partially causes the modifying of the focal properties of at least one of the first charged particle beam and the second charged particle beam.

C12.1. The system of paragraph C12, wherein the MEMS device comprises a structure defining a first aperture and a second aperture, and wherein the first charged particle beam passes through the first aperture and the second charged particle beam passes through the second aperture.

C12.1.1. The system of paragraph C12.1, wherein the first aperture has the same radius as the second aperture.

C12.1.2. The system of paragraph C12.1, wherein the first aperture has a smaller radius than the second aperture.

C12.1.3. The system of paragraph C12.1, wherein the first aperture has a greater radius than the second aperture.

C12.1.4. The system of any of paragraphs C12.1-C12.1.3, wherein the MEMS device comprises a surface layer facing

the plurality of charged particles, and wherein the first aperture and the second aperture are defined by the surface layer.

C12.1.4.1. The system of paragraph C12.1.4, wherein the surface layer is a foil.

C12.1.5. The system of any of paragraphs C12.1-C12.1.4.1, wherein the first aperture is an axial aperture positioned on an emission axis of the plurality of charged particles, and the second aperture is a non-axial aperture.

C12.1.6. The system of any of paragraphs C12.1-C12.1.4.1, wherein the second aperture is an axial aperture positioned on an emission axis of the plurality of charged particles, and the first aperture is a non-axial aperture.

C12.2. The system of any of paragraphs C12.1-C12.1.6, wherein the MEMS device comprises one or more electrodes.

C12.2.1. The system of paragraph C12.2, wherein when corresponding voltages are applied to the one or more electrodes, the one or more electrode generate the at least the quadrupole field.

C12.2.1. The system of any of paragraphs C12.2-12.2.1, wherein at least one of the one or more electrodes is grounded.

C12.2.2. The system of any of paragraphs C12.2-C12.2.1 when dependent from C12.1.4, wherein the MEMS device comprises an insulating layer that is opposite the surface layer.

C12.2.2.1. The system of paragraph C12.2.2, wherein the one or more electrodes are located in an electrode layer positioned between the insulating layer and the surface layer.

C12.2.3. The system of any of paragraphs C12.2-C12.2.2.1 wherein the one or more electrodes comprise four electrodes.

C12.2.4. The system of any of paragraphs C12.2-C12.2.2.1 wherein the one or more electrodes comprise seven electrodes.

C12.3. The system of any of paragraphs C12.1-C12.2.4, wherein the at least the quadrupole field is one of a dipole field, quadrupole field, hexapole field, or octupole field.

C12.4. The system of any of paragraphs C12.1-C12.3, wherein the at least the quadrupole field does not cause the focal planes of the first charged particle beam to be changed.

C12.5. The system of any of paragraphs C12.1-C12.4, wherein the MEMS device is further configured to generate one or more dipole fields.

C12.5.1. The system of paragraph C12.5, wherein the one or more dipole fields cause at least one of the charged particle beams to be deflected in a direction perpendicular to the emission axis.

C13. The system of any of paragraphs C1-C11, wherein the bifocal beamformer comprises: a physical structure defining a first aperture and a second aperture, wherein the first charged particle beam passes through the first aperture and the second charged particle beam passes through the second aperture; and a lens positioned and/or configured to adjust the focal properties of the at least one of the first charged particle beam and the second charged particle beam such that they have different focal planes.

C13.1. The system of paragraph C13, wherein the first charged particle beam passes through the first aperture and the second charged particle beam passes through the second aperture.

C13.2. The system of any of paragraphs C13-C13.1, wherein the lens is an einzel lens.

C13.3. The system of any of paragraphs C13-C13.2, wherein the lens is positioned above the physical structure.

C13.4. The system of any of paragraphs C13-C13.2, wherein the lens is positioned below above the physical structure.

C13.5. The system of any of paragraphs C13-C13.4, wherein the lens is positioned and/or configured to adjust the focal properties of the second charged particle beam.

C13.5.1. The system of paragraph C13.5, wherein the lens is not positioned and/or configured to adjust the focal planes of the first charged particle beam.

C14. The system of any of paragraphs C14-C14.5, wherein the bifocal beamformer comprises at least one physical structure that defines: a first aperture that allows the first charged particle beam to pass through the at least one physical structure; a second aperture that allows the second charged particle beam to pass through the at least one physical structure; and plurality of other apertures.

C14.1. The system of paragraph C14, wherein the plurality of other apertures form a pattern that creates an electromagnetic field that applies a lensing effect to the second charged particle beam during use of the bifocal beamformer.

C14.1.1. The system of paragraph C14.1, wherein the plurality of other apertures form a pattern that creates an electromagnetic field that applies at least a quadrupole lensing effect to the second charged particle beam during use of the bifocal beamformer.

C14.1.1.1. The system of paragraph C14.1.1, wherein the electromagnetic field does not apply the quadrupole lensing effect to the first charged particle beam during use of the bifocal beamformer.

C14.1.2. The system of any of paragraphs C14.1-C14.1.1.1, wherein the plurality of other apertures form a pattern that creates an electromagnetic field that applies a circular lensing effect to the first charged particle beam during use of the bifocal beamformer.

C14.1.2.1. The system of paragraph C14.1.2, wherein the plurality of other apertures form a pattern that creates an electromagnetic field that applies at least a circular lensing effect to the second charged particle beam during use of the bifocal beamformer.

C14.1.3. The system of any of paragraphs C14.1-C14.2.1, wherein the lensing effect applied by the electromagnetic field at least partially causes the modifying of the focal properties of at least one of the first charged particle beam and the second charged particle beam.

C14.1.3.1. The system of paragraph C14.1.3, wherein the electromagnetic field does change the focal planes of the first charged particle beam.

C14.3. The system of any of paragraphs C14-C14.2.1, wherein at least one aperture of the plurality of apertures is a hole.

C14.3.1. The system of paragraph C14.3, wherein the hole comprises:

an entrance defined in a first surface of the at least one physical structure, the first surface facing the plurality of charged particles; an exit defined in a second surface of the at least one physical structure that is opposite the first surface; and an empty volume that connects the entrance and the exit.

C14.3.1.1. The system of paragraph C14.3.1, wherein the first surface and the second surface are each surfaces of a single physical structure.

C14.3.1.2. The system of paragraph C14.3.1, wherein the first surface and the second surface are each surfaces of a different physical structures.

C14.4. The system of any of paragraphs C14-C14.3.1.2, wherein at least one aperture of the plurality of apertures is a cavity.

C14.4.1. The system of paragraph C14.4, wherein the cavity comprises:

an entrance defined in a first surface of the at least one physical structure, the first surface facing the plurality of charged particles; and an empty volume in communication with the entrance and defined by the at least one physical structure, wherein the at least one physical structure defines the empty volume such that a charged particle of the plurality of charged particles that enters the empty volume via the entrance does not pass through the bifocal beamformer.

C14.4.1.1. The system of paragraph C14.4.1, wherein the cavity is defined by a single physical structure.

C14.4.1.2. The system of paragraph C14.4.1, wherein the cavity is defined by multiple physical structures.

C14.5. The system of any of paragraphs C14.3-C14.4.1.2, wherein the plurality of apertures comprises a combination of holes and cavities.

C14.6. The system of any of paragraphs C14-C14.5, wherein the geometry of at least one of the first aperture, the second aperture, or an aperture of the plurality of apertures is circular.

C14.7. The system of any of paragraphs C14-C14.5, wherein the geometry of at least one of the first aperture, the second aperture, or an aperture of the plurality of apertures is rectangular.

C14.7.1. The system of any of paragraphs C14-C14.5, wherein the geometry of at least one of the first aperture, the second aperture, or an aperture of the plurality of apertures is a square.

C14.7.2. The system of any of paragraphs C14-C14.5, wherein the geometry of at least one of the first aperture, the second aperture, or an aperture of the plurality of apertures has rounded corners.

C14.8. The system of any of paragraphs C14-C14.7.2, wherein the geometries of the first aperture, the second aperture, and the plurality of apertures is not uniform.

C14.9. The system of any of paragraphs C14-C14.8, wherein the sizes of the first aperture, the second aperture, and the plurality of apertures is not uniform.

C14.10. The system of any of paragraphs C14-C14.9, wherein the bifocal beamformer further comprises a first electrode configured to receive a first applied voltage.

C14.10.1. The system of paragraph C14.10, wherein the first electrode comprises a physical structure that at least partially defines an electrode entrance aperture that allows at least a portion of the plurality of charged particles to pass through the first electrode.

C14.10.1.1. The system of paragraph C14.10.1, wherein the electrode entrance aperture is a first electrode entrance aperture that allows a first portion of the plurality of charged particles to pass through the first electrode, and the second electrode further defines a second electrode entrance aperture that allows a second portion of the plurality of charged particles to pass through the first electrode.

C14.10.2. The system of any of paragraphs C14.10-C14.10.1.1, wherein the first electrode is upstream of the first aperture, the second aperture, and the plurality of apertures.

C14.10.3. The system of any of paragraphs C14.10-C14.10.2, wherein the first electrode is a disk shaped electrode.

C14.10.4. The system of any of paragraphs C14.10-C14.10.2, wherein the bifocal beamformer further comprises a second electrode configured to receive a second applied voltage.

C14.10.4.1. The system of paragraph C14.10.4, wherein the first voltage is different from the second voltage.

C14.10.4.2. The system of paragraph C14.10.4, wherein the first voltage and the second voltage are different.

C14.10.4.3. The system of any of paragraphs C14.10.4-C14.10.4.2, wherein the second electrode comprises a physical structure that at least partially defines an electrode exit aperture that at least one of the first charged particle beam and the second charged particle beam to pass through the second electrode.

C14.10.4.3.1. The system of paragraph C14.10.4.3, wherein the electrode exit aperture is a first electrode exit aperture that allows the first charged particle beam to pass through the second electrode, and the second electrode further comprises a second electrode exit aperture that allows the second charged particle beam to pass through the second electrode.

C14.10.4.3. The system of any of paragraphs C14.10.4-C14.10.4.3.1, wherein the second electrode is positioned downstream of the first aperture, the second aperture, and the plurality of apertures.

C15. The system of any of paragraphs C1-C11, wherein the bifocal beamformer comprises a biprism that defines a hole, and which is positioned and/or configured to split the plurality of charged particles into the first charged particle beam and the second charged particle beam.

C16. The system of any of paragraphs C1-C11, wherein laser pattern fringes are used to split the plurality of charged particles into the first charged particle beam and the second charged particle beam.

C17. The system of any of paragraphs C1-C16, wherein the second charged particle beam is focused at a different plane located above the sample.

C17.1. The system of paragraph C17, wherein the different plane is located at least at least 0.1%, 1%, 10%, or 100% of the objective lens focal distance above the sample.

C18. The system of any of paragraphs C1-C16, wherein the second charged particle beam is focused at a different plane located below the sample.

C18.1. The system of paragraph C18, wherein the different plane is located at least 0.1%, 1%, 10%, or 100% of the objective lens focal distance below the specimen the sample.

C19. The system of any of paragraphs C17-C18.1, wherein the distance between the plane at or near the sample and the different plane is at least 0.1%, 1%, 10%, or 100% of the objective lens focal distance.

C20. The system of any of paragraphs C1-C19, wherein the second charged particle beam is a parallel beam at the sample.

C21. The system of any of paragraphs C1-C19, wherein the second charged particle beam is a convergent beam at the sample.

C22. The system of any of paragraphs C1-C19, wherein the second charged particle beam is a divergent beam at the sample.

Dl. Use of the system of any of paragraphs C1-C20 to perform any of the methods of paragraphs A1-A16, B1-B15, L1-L10.2, or M9.1.

E1. A non-transitory computer readable media comprising instructions that, when executed by one or more processing units, cause the system of any of paragraphs C1-C20 to perform any of the methods of paragraphs A1-A16, B1-B15, L1-L10.2, or Ml-M9.1.

F1. A MEMS device, comprising: a physical structure that defines: a first aperture configured to allow a first portion of charged particles of a plurality of charged particles to pass through the MEMS device; and a second aperture configured

to allow a second portion of charged particles of the plurality of charged particles to pass through the MEMS device; and one or more electrodes configured to, when corresponding voltages are applied to the one or more electrodes, generate at least a quadrupole field that at least partially causes a modification of the focal properties of at least one of the first portion of charged particles and the second portion of charged particles.

F1.1. The MEMS device of paragraph F1, wherein the plurality of charged particles form a source beam that is incident on the MEMS device.

F1.1.1. The MEMS device of any of paragraphs F1-F1.1, wherein the plurality of charged particles are a plurality of electrons.

F2. The MEMS device of any of paragraphs F1-F1.1.1, wherein the first aperture is configured to form the first portion of charged particles into a first charged particle beam and the second aperture is configured to form the second portion of charged particles into a second charged particle beam.

F2.1. The MEMS device of paragraph F2, wherein the first aperture has the same radius as the second aperture.

F2.2. The MEMS device of paragraph F2, wherein the first aperture has a smaller radius than the second aperture.

F2.3. The MEMS device of paragraph F2, wherein the first aperture has a greater radius than the second aperture.

F3. The MEMS device of any of paragraphs F1-F2.3, wherein the physical structure comprises a surface layer that defines the first aperture and the second aperture.

F3.1. The MEMS device of paragraph F3, wherein the surface layer prevents a third portion of charged particles from passing through the MEMS device.

F3.2. The MEMS device of any of paragraphs F3-F3.1, wherein the surface layer is a foil.

F4. The MEMS device of any of paragraphs F1-F3.2, wherein the first aperture is an axial aperture positioned on an emission axis of the plurality of charged particles, and the second aperture is a non-axial aperture.

F5. The MEMS device of any of paragraphs F1-F3.2, wherein the second aperture is an axial aperture positioned on an emission axis of the plurality of charged particles, and the first aperture is a non-axial aperture.

F6. The MEMS device of any of paragraphs F1-F5, wherein at least one of the one or more electrodes is grounded.

F7. The MEMS device of any of paragraphs F1-F6 when dependent from any of paragraphs F3-F3.1, wherein the MEMS device comprises an insulating layer that is opposite the surface layer.

F7.1. The MEMS device of paragraph F7, wherein the one or more electrodes are located in an electrode layer positioned between the insulating layer and the surface layer.

F8. The MEMS device of any of paragraphs F1-F7.1, wherein the one or more electrodes comprise four electrodes.

F9. The MEMS device of any of paragraphs F1-F7.1, wherein the one or more electrodes comprise seven electrodes.

F10. The MEMS device of any of paragraphs F1-F9, wherein the at least the quadrupole field is one of a dipole field, quadrupole field, hexapole field, or octupole field.

F11. The MEMS device of any of paragraphs F1-F10, wherein the at least the quadrupole field does not cause the focal planes of the first charged particle beam to be changed.

F12. The MEMS device of any of paragraphs F1-F11, wherein the MEMS device is further configured to generate one or more dipole fields.

F12.1. The MEMS device of paragraph F12, wherein the one or more dipole fields cause at least one of the charged particle beams to be deflected in a direction perpendicular to the emission axis.

G1. Use of any of the MEMS devices of any of paragraphs F1-F12.1.

G2. Use of any of the MEMS devices of paragraphs F1-F12.1 to perform any of the methods of paragraphs A1-A16, B1-B15, L1-L10.2, or Ml-M9.1.

G3. The use of any of the MEMS devices of paragraphs F1-F12.1 for investigation of a sample.

H1. Use of any of the MEMS devices of paragraphs F1-F12.1 in a system of any of paragraphs C1-C20.

I1. An aperture lens array device comprising: at least one physical structure that defines: a first aperture configured to allow a first portion of charged particles of a plurality of charged particles to pass through the aperture lens array device; a second aperture configured to allow a second portion of charged particles of the plurality of charged particles to pass through the aperture lens array device; plurality of other apertures; and at least one electrode, wherein the first aperture, the second aperture, and the plurality of other apertures form a pattern that, when corresponding voltages are applied to the at least one physical structure and at least one electrode, produces an electromagnetic field that applies a lensing effect to the second portion of charged particles during use of the aperture lens array device.

I1.1. The aperture lens array device of paragraph I1, wherein the plurality of charged particles form a source beam that is incident on the aperture lens array device.

I1.1.1. The aperture lens array device of any of paragraphs I1-I1.1, wherein the plurality of charged particles are a plurality of electrons.

I2. The aperture lens array device of any of paragraphs I.1-I1.1.1, wherein the first aperture is configured to form the first portion of charged particles into a first charged particle beam and the second aperture is configured to form the second portion of charged particles into a second charged particle beam.

I2.1. The aperture lens array device of paragraphs I2, wherein the electromagnetic field applies at least a quadrupole lensing effect to the second charged particle beam during use of the aperture lens array device.

I2.1.1. The aperture lens array device of paragraph I2.1, wherein the electromagnetic field does not apply the quadrupole lensing effect to the first charged particle beam during use of the aperture lens array device.

I2.1.2. The aperture lens array device of any of paragraphs I2-I2.1.1, wherein the electromagnetic field applies a circular lensing effect to the first charged particle beam during use of the aperture lens array device.

I2.1.3. The aperture lens array device of any of paragraphs I2-I2.1.2, wherein the electromagnetic field that at least a circular lensing effect to the second charged particle beam during use of the aperture lens array device.

I3. The aperture lens array device of any of paragraphs I1-I2.1.3, wherein the lensing effect applied by the electromagnetic field at least partially causes a modification of the focal planes of at least one of the first charged particle beam and the second charged particle beam.

I3.1. The aperture lens array device of paragraph I1, wherein the modification of the focal planes caused by the lensing effect causes the first charged particle beam and the second charged particle beam to have different focal planes.

I3.2. The aperture lens array device of any of paragraphs I3-I3.1, wherein the electromagnetic field does change the focal planes of the first charged particle beam.

I4. The aperture lens array device of any of paragraphs I1-I3.2, wherein at least one aperture of the plurality of apertures is a hole.

I4.1. The aperture lens array device of paragraph I4, wherein the hole comprises: an entrance defined in a first surface of the at least one physical structure, the first surface facing the plurality of charged particles; an exit defined in a second surface of the at least one physical structure that is opposite the first surface; and an empty volume that connects the entrance and the exit.

I4.1.1. The aperture lens array device of paragraph I4.1, wherein the first surface and the second surface are each surfaces of a single physical structure.

I4.1.2. The aperture lens array device of paragraph I4.1, wherein the first surface and the second surface are each surfaces of a different physical structures.

I5. The aperture lens array device of any of paragraphs I1-I4.1.2, wherein at least one aperture of the plurality of apertures is a cavity.

I5.1. The aperture lens array device of paragraph I5, wherein the cavity comprises: an entrance defined in a first surface of the at least one physical structure, the first surface facing the plurality of charged particles; and an empty volume in communication with the entrance and defined by the at least one physical structure, wherein the at least one physical structure defines the empty volume such that a charged particle of the plurality of charged particles that enters the empty volume via the entrance does not pass through the bifocal beamformer.

I5.1. The aperture lens array device of paragraph I5.1, wherein the cavity is defined by a single physical structure.

I5.2. The aperture lens array device of paragraph I5.1, wherein the cavity is defined by multiple physical structures.

I6. The aperture lens array device of any of paragraphs I4-I5.2, wherein the plurality of apertures comprises a combination of holes and cavities.

I7. The aperture lens array device of any of paragraphs I1-I6, wherein the geometry of at least one of the first aperture, the second aperture, or an aperture of the plurality of apertures is circular.

I8. The aperture lens array device of any of paragraphs I1-I7, wherein the geometry of at least one of the first aperture, the second aperture, or an aperture of the plurality of apertures is rectangular.

I9. The aperture lens array device of any of paragraphs I1-I8, wherein the geometry of at least one of the first aperture, the second aperture, or an aperture of the plurality of apertures is a square.

I10. The aperture lens array device of any of paragraphs I1-I9, wherein the geometry of at least one of the first aperture, the second aperture, or an aperture of the plurality of apertures has rounded corners.

I11. The aperture lens array device of any of paragraphs I1-I10, wherein the geometries of the first aperture, the second aperture, and the plurality of apertures is not uniform.

I12. The aperture lens array device of any of paragraphs I1-I11, wherein the sizes of the first aperture, the second aperture, and the plurality of apertures is not uniform.

I13. The aperture lens array device of any of paragraphs I1-I12, wherein the at least one electrode comprises a first electrode configured to receive a first applied voltage.

I13.1. The aperture lens array device of paragraph I13, wherein the first electrode comprises a physical structure that at least partially defines an electrode entrance aperture that allows at least a portion of the plurality of charged particles to pass through the first electrode.

I13.1.1. The aperture lens array device of paragraph I13.1, wherein the electrode entrance aperture is a first electrode entrance aperture that allows a first portion of the plurality of charged particles to pass through the first electrode, and the second electrode further defines a second electrode entrance aperture that allows a second portion of the plurality of charged particles to pass through the first electrode.

I13.2. The aperture lens array device of any of paragraphs I13-I13.1.1, wherein the first electrode is upstream of the first aperture, the second aperture, and the plurality of apertures.

I13.3. The aperture lens array device of any of paragraphs I13-113.2, wherein the first electrode is a disk shaped electrode.

I13.4. The aperture lens array device of any of paragraphs I13-113.3, wherein the at least one electrode further comprises a second electrode configured to receive a second applied voltage.

I13.4.1. The aperture lens array device of paragraph I13.4, wherein the first voltage is different from the second voltage.

I13.4.2. The aperture lens array device of paragraph I13.4, wherein the first voltage and the second voltage are the same.

I13.4.3. The aperture lens array device of any of paragraphs I13.4-113.4.2, wherein the second electrode comprises a physical structure that at least partially defines an electrode exit aperture that at least one of the first charged particle beam and the second charged particle beam to pass through the second electrode.

I13.4.3.1. The aperture lens array device of paragraph I13.4.3, wherein the electrode exit aperture is a first electrode exit aperture that allows the first charged particle beam to pass through the second electrode, and the second electrode further comprises a second electrode exit aperture that allows the second charged particle beam to pass through the second electrode.

I13.4.4. The aperture lens array device of any of paragraphs I13.4-113.4.3.1, wherein the second electrode is positioned downstream of the first aperture, the second aperture, and the plurality of apertures.

J1. Use of the multi-aperture device of any of paragraphs I1-I13.4.4.

J2. Use of the multi-aperture device of any of paragraphs I1-I13.4.4 to perform any of the methods of paragraphs A1-A16, B1-B15, L1-L10.2, or M9.1.

J3. The use of the multi-aperture device of any of paragraphs I1-113.4.4 for investigation of a sample.

Kl. Use of the multi-aperture device of any of paragraphs I1-113.4.4 in a system of any of paragraphs C1-C20.

L1. A method for investigating a sample with TEM and SEM techniques, the method comprising: emitting a plurality of electrons toward a sample; forming the plurality of electrons particles into a first electron beam and a second electron beam; modifying the focal properties of at least one of the first electron beam and the second electron beam such that: the first electron beam a SEM beam that is focused at a plane at or near the sample; and the second electron beam is a TEM beam that is parallel beam when incident on the sample; detecting emissions resultant from the SEM beam and the TEM beam being incident on the sample.

L2. The method of paragraph L1, further comprising generating one or both of a SEM image and TEM image from the detected emissions resultant from the SEM beam and the TEM beam being incident on the sample.

L3. The method of any of paragraph L1-L2, wherein detecting emissions resultant from the SEM beam and the TEM beam being incident on the sample comprises detecting (1) emissions resultant from the SEM beam being incident and (2) emissions resultant from the TEM beam being incident on the sample, using a same detector and/or detector array.

L4. The method of any of paragraph L1-L3, wherein detecting emissions resultant from the SEM beam and the TEM beam being incident on the sample comprises detecting (1) emissions resultant from the SEM beam being incident and (2) emissions resultant from the TEM beam being incident on the sample, at the same time.

L4.1. The method of paragraph L4, further comprising scanning the SEM beam across a surface region of the sample.

L4.1.1. The method of paragraph L4.1, wherein the TEM beam remains incident on the sample while the SEM beam is scanned.

L4.1.2. The method of any of paragraphs L4.1-L4.1.1, wherein the TEM beam remains incident on a static location while the SEM beam is scanned.

L5. The method of any of paragraph L1-L4.1, further comprising switching between two of a SEM mode of operation, a TEM mode of operation, and a simultaneous SEM/TEM mode of operation.

L5.1. The method of paragraph L5, wherein switching to the SEM mode of operation comprises causing the TEM beam to be blocked so that only the SEM beam is incident on the sample.

L5.1.1. The method of paragraph 5.1, wherein causing the TEM beam to be blocked comprises one of: deflecting the TEM beam so that it is blocked by a beam blocker; moving a beam blocker such that the beam blocker obstructs the path of the TEM beam; and obstructing an aperture so that the TEM beam cannot pass through the aperture.

L5.2. The method of any of paragraph L5-L5.1, wherein switching to the TEM mode of operation comprises causing the SEM beam to be blocked so that only the TEM beam is incident on the sample.

L5.2.1. The method of paragraph 5.2, wherein causing the SEM beam to be blocked comprises one of: deflecting the SEM beam so that it is blocked by a beam blocker; moving a beam blocker such that the beam blocker obstructs the path of the SEM beam; and obstructing an aperture so that the SEM beam cannot pass through the aperture.

L6. The method of any of paragraphs L1-L5.2.1., further comprising determining a portion of the detected emissions that is attributable to the TEM beam being incident on the sample.

L6.1. The method of paragraph L6, further comprising determining a portion of the detected emissions that is attributable to the SEM beam being incident on the sample.

L7. The method of any of paragraphs L1-L6.1, further comprising generating a SEM image based on the detected emissions resultant from the SEM beam and the TEM beam being incident on the sample.

L8. The method of any of paragraphs L1-L7, further comprising generating a TEM image based on the detected emissions resultant from the SEM beam and the TEM beam being incident on the sample.

L9. The method of any of paragraphs L1-L8, wherein the emissions resultant from the SEM beam and the TEM beam being incident on the sample are detected with a single detector and/or detector array.

L10. The method of any of paragraphs L1-L9, wherein the forming of the plurality of electrons particles into a first electron beam and a second electron beam and the modification of the focal properties is performed at least in part by a bifocal beamformer.

L10.1. The method of paragraph L10, wherein the bifocal beamformer is a MEMS device of any of paragraphs F1-F12.1.

L10.2. The method of paragraph L10, wherein the bifocal beamformer is a multi aperture array of any of paragraphs I1-I13.4.4.

L10.2. The method of any of paragraphs L10-L10.2, wherein the bifocal beamformer applies at least a quadrupole lensing effect to one of the first electron beam and the second electron beam.

What is claimed is:

1. A method for using electron holography to investigate a sample, the method comprising

emitting a plurality of electrons toward the sample;

forming the plurality of electrons into a first electron beam and a second electron beam;

modifying the focal properties of at least one of the first electron beam and the second electron beam such that the two electron beams have different focal planes;

focusing the first electron beam such that it has a focal plane at or near the sample;

focusing the second electron beam so that it is incident on the sample, and has a focal plane in the diffraction plane;

detecting an interference pattern of the first electron beam and the diffracted second electron beam in the diffraction plane;

determining an exit wave function of the exit wave resultant from the second electron beam being incident on the sample; and

determining the structure of the sample based on the exit wave function.

2. The method of claim **1**, wherein the sample is a crystal, and determining the structure of the sample comprises determining the crystal lattice of the sample based on the exit wave function.

3. The method of claim **1**, where determining the exit wave function comprises determining the exit wave function of the electrons leaving the sample in response to the second electron beam being incident on the sample, and wherein the structure of the sample is determined based on the exit wave function.

4. The method of claim **3**, where determining the exit wave function comprises determining the phase and amplitude of the exit wave function of the electrons leaving the sample in response to the second electron beam being incident on the sample.

5. The method of claim **1**, wherein modifying the focal properties of at least one of the first electron beam and the second electron beam comprises applying at least a quadrupole lens action to one of the first electron beam and the second electron beam.

6. The method of claim **1**, wherein the diffraction plane corresponds to the first focal plane of the second electron beam downstream of the sample.

7. A method for using electron holography to investigate a sample, the method comprising

emitting a plurality of electrons toward the sample;

forming the plurality of electrons into a first electron beam and a second electron beam;

modifying the focal properties of at least one of the first electron beam and the second electron beam such that the two electron beams have different focal planes;

focusing the first electron beam such that it has a focal plane at or near the sample;

focusing the second electron beam so that it is incident on the sample, and has a focal plane in the diffraction plane; and

detecting an interference pattern of the first electron beam and the diffracted second electron beam in the diffraction plane.

8. The method of claim **7**, further comprising generating a hologram image of the sample based on the interference pattern of the first electron beam and the diffracted second electron beam in the diffraction plane.

9. The method of claim **7**, further comprising determining the relative phases of electrons diffracted by the sample based on the interference pattern of the first electron beam and the diffracted second electron beam in the diffraction plane.

10. The method of claim **7**, further comprising determining an exit wave function of the electrons leaving the sample in response to the second electron beam being incident on the sample.

11. The method of claim **10**, where determining the exit wave function comprises determining the phase and amplitude of the exit wave function of the electrons leaving the sample in response to the second electron beam being incident on the sample.

12. The method of claim **10**, further comprising determining the structure of the sample based on the exit wave function.

13. The method of claim **12**, wherein the sample is a crystal, and determining the structure of the sample comprises determining the crystal lattice of the sample based on the exit wave function.

14. The method of claim **7**, wherein the diffraction plane corresponds to the first focal plane of the second electron beam downstream of the sample.

15. The method of claim **7**, wherein the first electron beam and the second electron beam are coherent.

16. The method of claim **7**, wherein the first electron plane passes through an aperture in the sample.

17. The method of claim **16**, wherein the method further comprises, burning the aperture in the sample with one of an electron beam and an ion beam.

18. The method of claim **7**, further comprising:

applying a phase shift to the first electron beam;

detecting an additional interference pattern of the phase shifted first electron beam and the diffracted second electron beam in the diffraction plane; and

determining a phase of the wave function of a sample exit wave in the diffraction plane based at least in part on the interference pattern and the additional interference pattern, wherein the sample exit wave is resultant from the second electron beam being incident on the sample.

19. The method of claim **7**, wherein a second diameter of the second electron beam is greater than 20 times larger than a first diameter of the first electron beam.

20. The method of claim **7**, wherein modifying the focal properties of at least one of the first electron beam and the second electron beam comprises applying at least a quadrupole lens action to one of the first electron beam and the second electron beam.

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